Final Project Report

for

Study of the Relationship of Noise and Component Reliability

(1 Feb. 1965 - 15 Dec. 1965)

Contract No.: NAS5-9550

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for

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INTRODUCTION

It has been known for many years that high current density areas generate an excessive amount of 1/f noise in semiconductor materials. The application of this phenomena has been most useful in the area of resistor, transistor and diode manufacture. In the transistor field most of the past information has been on germanium transistors. Noise has been used most successfully as a screening tool for detecting erratic collector-base junctions, due to either contamination or what would be considered an early avalanche caused by irregularities within or on the periphery of the junction. Also high current densities in the emitter region caused by fractures or junction irregularities are detected. Little work prior to this study had been done on the planar type silicon transistors. The mechanism which generates the 1/f noise should be equally applicable to the silicon transistor as it has been to the germanium type. Transistors having small cross section areas such as the high frequency types, should, by their nature, generate more 1/f noise than those having a broader or larger cross sectional area. It is the purpose of this study to determine the correlation of a noise measurement and the failure of the transistor and to establish a "cull line" for screening the transistors so that the expense of burn-in of the device could be eliminated or at least reduced to a minimum. Every effort was made to perform the tests based solely on a noise measurement so as not to bias the experiment with other measurements, such as leakage and hfe. It was necessary to evaluate several transistor manufacturers to determine one which would be suitable for the study program.

SELECTION OF TRANSISTOR MANUFACTURER

The initial phase of the study was to determine which of six different manufacturers would be the most suitable for the study program. 100 transistors of the type 2N1613 were purchased from each of the six manufacturers, all being major manufacturers in this country. These transistors were measured at two different frequencies under operating conditions of 30V 0.1 milliamperes with a source impedance of 10K ohms. The measurements were made at 100 cycles and 1 KC. The histograms Nos. 1 - 6 show the distribution of these measurements. In addition, noise measurements were made with a collector voltage of 10 volts, collector current of 30 milliamperes, and a source impedance of 0 ohms. These measurements were also made at 100 cycles and 1 KC. Histograms of the measurements are shown in figures 7 - 12. It should be noted that there is a reasonable difference in the distribution between manufacturers. Manufacturer No 3 was chosen because the transistors from that source showed a reasonable, but not excessive distribution for both noise measurements. This group also contained several units showing an erratic breakdown between base and emitter when biased in the reverse direction.

The scatter plots, figures 13 - 18 show the correlation between the 1 KC noise measurements and the 100 cycle noise measurements for each of the six groups measured. It can be seen from these plots that all groups were predominantly 1/f although the spread of the distributions was considerably different. It is the 1/f noise that is generated from transistor defects, such as areas of high current density caused by fractures, poor formation of junctions and surface contaminants, which should be the key to correlation between the noise and failure of the transistor under operation. An additional scatter plot, figure 19, was made for the transistor group (manufacturer #3) which was selected. This plot shows the correlation between the 30V, 0.1 Milliampere and the 10V, 30 milliampere tests. It can be seen that there was very little correlation between these two measurements. Since equipment was nearly available to make measurements at 10 cycles which would show more clearly the 1/f characteristics, the program was delayed for approximately 6 weeks until the instrumentation was available. From that time on measurements were made at 10 cycles, 100 cycles and 1 KC. The correlation between these measurements, as would be expected, was similar to the previous scatter plots shown.

A total of 3000 commercial grade 2N1613 transistors were purchased from the selected manufacturer for the test. Each of the transistors was measured for noise at the three different frequencies under two test conditions. The conditions for Test A were $V_{ce} = 30V$, $I_c = 0.1$ MA, and $R_g = 10K$. The conditions for Test B were $V_{ce} = 10V$, $I_c = 30$ MA, and $R_g = 0$. It was noted that the cases of the transistors had two code groups indicating that they had come from two different manufacturing lines or were manufactured at two different times. The histogram shown in figure 20 shows the distribution of the noise parameter Test A at 10 cycles. Figures 21, 22 and 23 show the Test A for the code groups N and Q. There was no significant difference between the two groups. It can be seen from figures 24, 25 and 26 that there was also no significant difference in the distribution of the Test B noise measurements.

SELECTION OF TRANSISTORS FOR TEST

Since it was economically unfeasible to test the entire 3000 transistors, 500 transistors were selected. These transistors were selected to give as nearly as possible, a uniform distribution as a function of the noise parameter. Some additional weighting was given to the transistors in the excessively noisy group, that is in excess of 1300 nanovolts for Test A and 100 nanovolts for Test B. Additional weighting was also given to those transistors falling within the norm of the histogram. To select the 500 transistors, a cross plot of the 10 cycle measurements of both Test A and Test B was made. Referring to figure 28, the large number in the center of each box indicates the number of transistors of the 3000 units for each magnitude of Test A and B. The small number in the corner of the box indicates the number of units selected from that box. The units were selected at random from each box, except where all were included. The transistors were then placed on plug-in type printed circuit boards with five to each board for convenience of measurement and ageing of the transistor with minimal handling. Figures 29 - 30 show the distribution of the selected transistors for the study for Tests A and B respectively.

TEST CONDITIONS

Several manufacturers' specifications were obtained to determine the maximum operating conditions for the test, to make sure there was agreement between the specifications. The conditions for operation were as follows:

100° C free air ambient 50V collector voltage and 9 milliamperes collector current .

Each transistor was fused with 1/4 ampere fuse to prevent overloading the power source in the event of a short circuit. Prior to insertion in the oven and the application of power, a measurement of Icbo, Iebo, hfe and a recheck of the noise Tests A and B was made. There was no appreciable change in the noise measurements and the distribution of Icbo, Iebo and hfe of the selected 500 as shown in figures 31, 32 and 33. There was no correlation between any of these measurements and the noise measurements, with the exception of those units showing excessive leakage, that is of 1 microampere or greater, and the few units whose hfe was 0 as indicated by a shorted unit. The transistors were separated into three groups consisting of 150 in groups 1 and 2 and 200 in group 3. The three groups were placed in the oven at staggered starting times for the test. This was done to facilitate the periodic measurements to be made during the test. Each group was removed from the oven at 24, 72, 168, 504 and 1008 hours. During each of these removals noise tests A and B were made at the three different frequencies as well as measurement of Icbo, Iebo and hfe. Before returning any group to the oven for further tests, the data was quickly scanned and crosschecked with the data of the previous test. Where discontinuities or irregularities in any measurement occurred, the unit was rechecked. At the end of the tests, the data was analyzed to determine the correlation between noise tests A and/or B and the failure of the transistor.

DATA ANALYSIS

There were three basic failure criteria that were considered; excessive Icbo or Iebo or a change in hfe. With the exception of a few units which failed catastrophically, the Icbo measurement was the only one of significance and as a result was used as the failure criterion. Since such strong correlation existed between the 10 cycle, 100 cycle and 1000 cycle measurements, the data of the 10 cycle only is included. The histograms of failure distribution were based on an Icbo in excess of 100 nanoamperes, 30 nanoamperes and 10 nanoamperes. These are shown on the histogram as different shades in the columns. Those units in excess of 100 nanoamperes are shown at the bottom of each column. By comparing the failure distribution of the 10 cycle Test A and the original distribution, it can be seen that there was very little correlation with the exception of the very noisy units. Test B however, shows that approximately 50% of the failures had a noise in excess of 100 nanovolts per root cycle. To show the degree of correlation of Test B and a failure criterion of Icbo equal to or greater than 100 nanoamperes, the percentage of failures in a given noise group was divided by the percentage of the total. This was normalized to apply to the entire 3000 transistor group, assuming that the transistors tested were typical of the group. These ratios are shown in Table 1.

TABLE 1

Test B nv per root cycle	% Failure % total removed	Cum. % Failure % total removed
130	3.60	3.60
120	0.44	2.70
110	1.85	2.50
100	1.80	2.30
90	2.50	2.30
80	4.15	2.70
70	1.47	2.50
60	0.58	1.85
50	0.70	1.48
40	1.20	1.35
30	0.21	1.05
20	0.00	1.00

If a failure was purely a random process and there was no correlation, the ratio would be unity. It can be seen that with one exception, transistors having a noise in excess of 70 nanovolts have a ratio of from 1.8 to as high as 4.15, showing a distinct correlation between the noise measurement and a failure of Icbo. There was no noticeable correlation between Icbo, Iebo and hfe with the exception of the few units having excessive initial leakage or 0 hfe.

Using a failure criterion of 100 nanoamperes Icbo, a failure rate vs time was plotted as shown in figure 39. The 0 hour failures were excluded from this plot since it was not known whether they failed during tests by the manufacturer or during the initial screening for this study program. The reduction in failure rate for the first 168 hours was essentially exponential; however, from 168 hours to 1000 hours, the rate was a constant, indicating a failure mechanism which would probably have an end of life peak for this type of operation. Figure 40 shows the cumulative failure of units as a function of test time. The noise code for this histogram was chosen to include essentially the first, second and third sigma limits.

It is easy to see that no units in the low noise category that is less than 60 nanovolts, failed during the first 72 hours of test and that only two units had failed at 168 hours. The failures which occurred from there on showed little or no correlation with the noise measurement. An attempt was made to measure the thermal resistance of a number of the transistors. The difficulty of making this measurement and the accuracy of such a measurement did not warrant including the data in this report. A correlation between the failures and the effective operating temperature of the junctions should exist. Hot spots generated by high current density areas cannot be determined by normal junction temperature based on Vbe or leakage measurements and as a result such measurements would not be sufficient. A measurement of the 1/f noise generated would be more informative. The histograms shown in figures 41 - 44 show the noise distribution for both tests A and B at 24 hours as well as the failure distribution for the same measurements based on the 24 hour test. Here again a strong correlation is shown between the failure of Icbo and the noise test B.

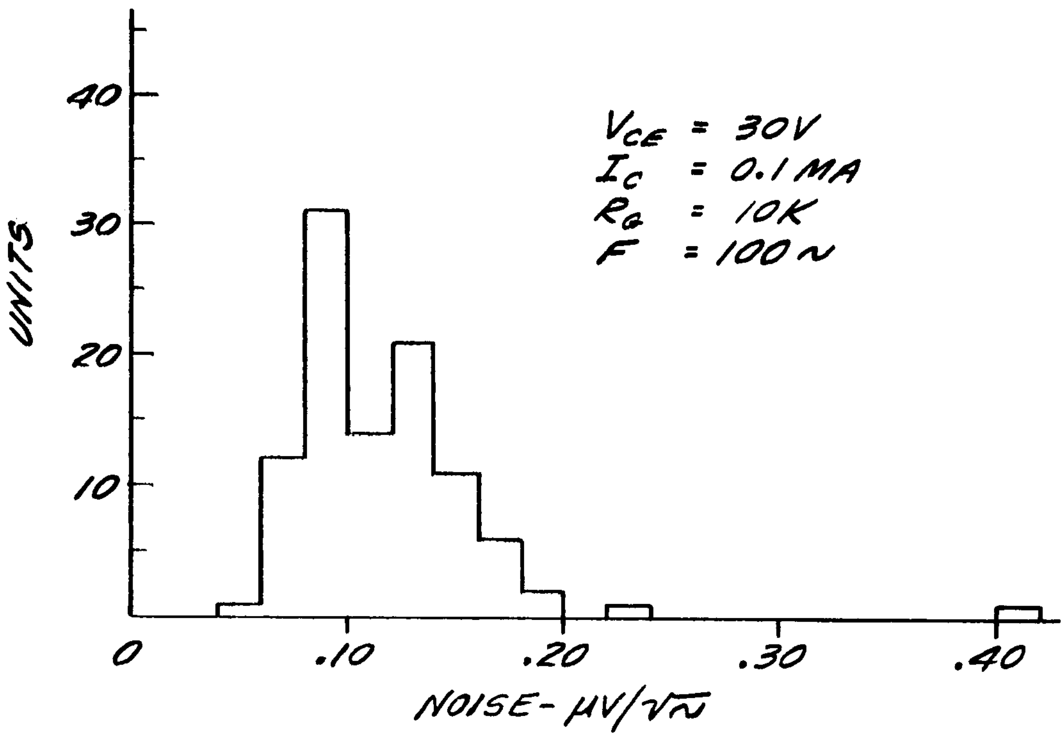
CONCLUSION

There were two basic facts learned from this study program; first, there was excellent correlation between failure and an initial noise measurement using a collector current of 30 milliamperes and a zero source impedance up to and including 72 hours of operation at maximum operating conditions, and secondly, that there is a failure mechanism occurring which did not correlate with any measurements, noise, leakage or hfe. It is believed that this is due to excessive dissipation in the device. If a burn-in test were used at a lower dissipation, it is most likely that those failures showing for test times in excess of 168 hours would be greatly delayed or perhaps not occur at all. Although it would require extensive examination of the failed transistors, there is every reason to believe that the 1/f noise generated in Test B was due to high current density arising within the transistor caused by fractures or malformed junctions having irregularities such as pipes or spikes. Therefore such a noise screening test is of great value and could remove a burn-in test for screening of potential failures. It should be remembered that the transistors chosen for this test had a rather broad distribution for the noise parameters, indicating a need for tighter process control and it is not surprising to find a reasonably high failure rate of such a device.

RECOMMENDATIONS

To obtain a clearer picture of early failure versus noise measurements the aging operating conditions should be reduced perhaps to one half maximum rated dissipation. The maximum dissipation conditions of this study program caused the basic issue to be greatly clouded after approximately 168 hours of aging. If the 2N1613 transistor is to receive a burn-in by NASA it is recommended that a noise test (Vce=10v, Ic=30 ma and Rg=0 ohms) be made. The higher noise units (ie 20%) of a 10 cycle, 100 cycle or even a 1 Kc noise measurement should be separated. After burn-in and the failures are accounted for it should be simple to confirm the conclusions of this study. It is expected that a well screened group of transistors will not have as many failures nor will there be as many noisy units, thus fewer units will have to be removed.

FIGURE 1
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER #I
TEST A



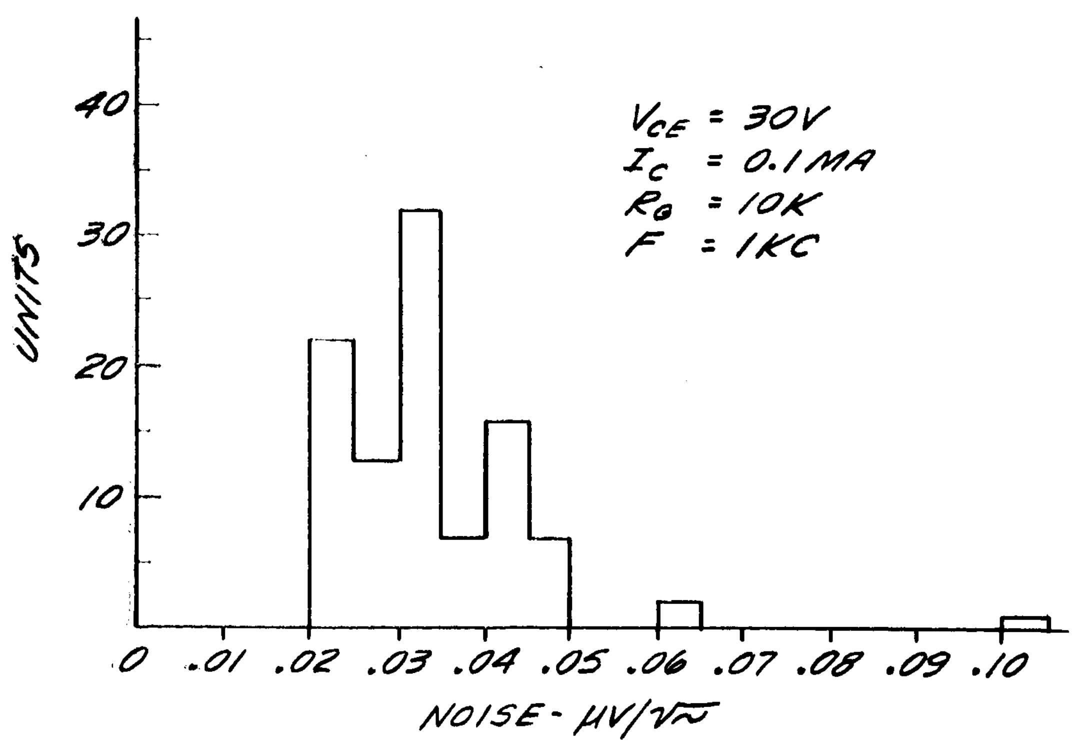
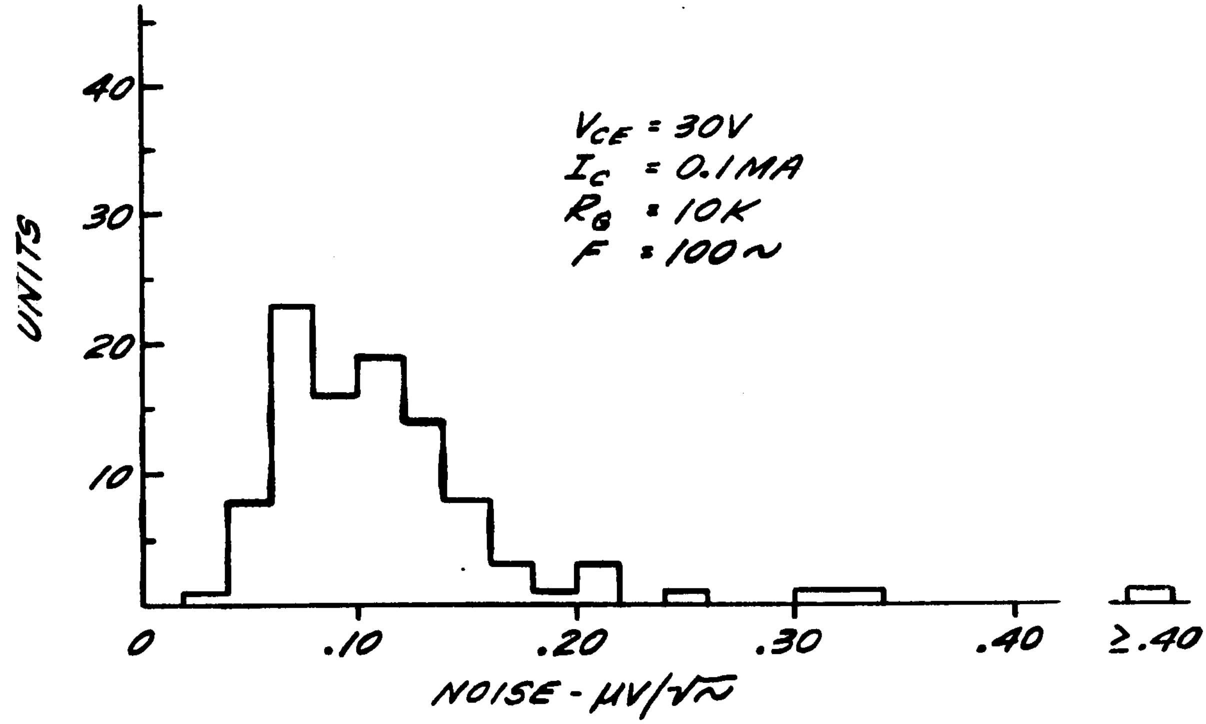


FIGURE 2
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER #II
TEST A



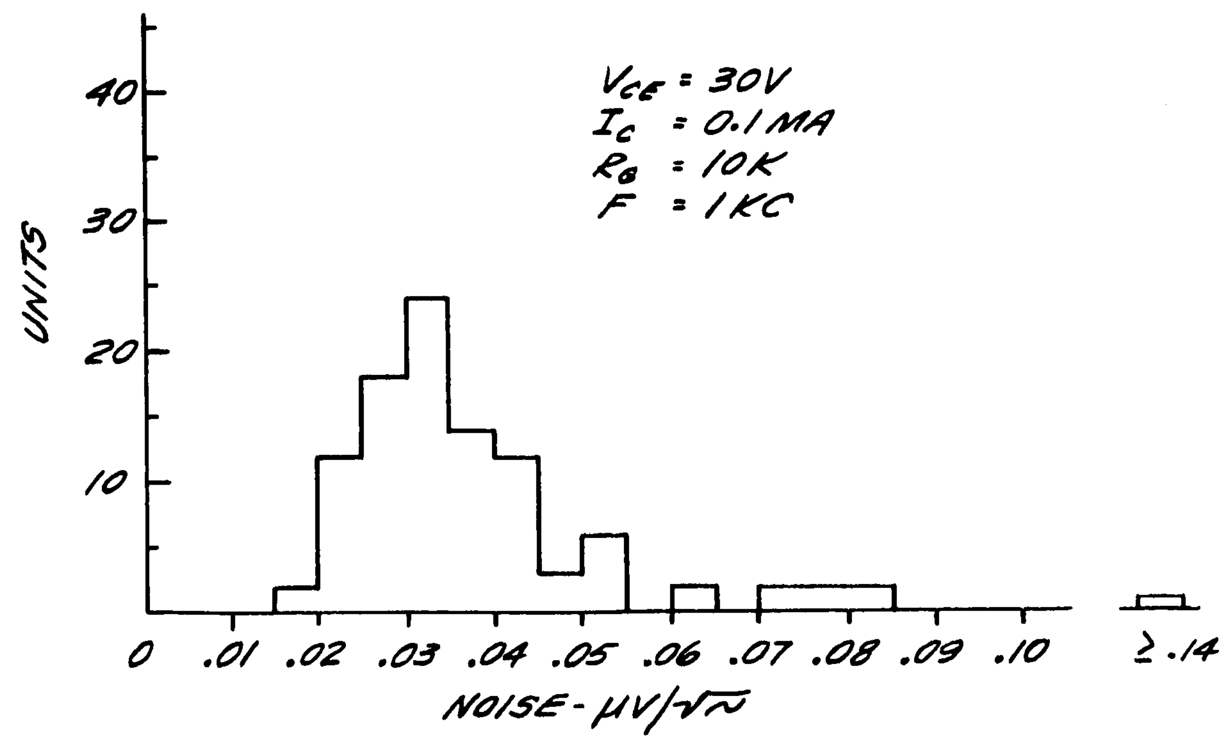
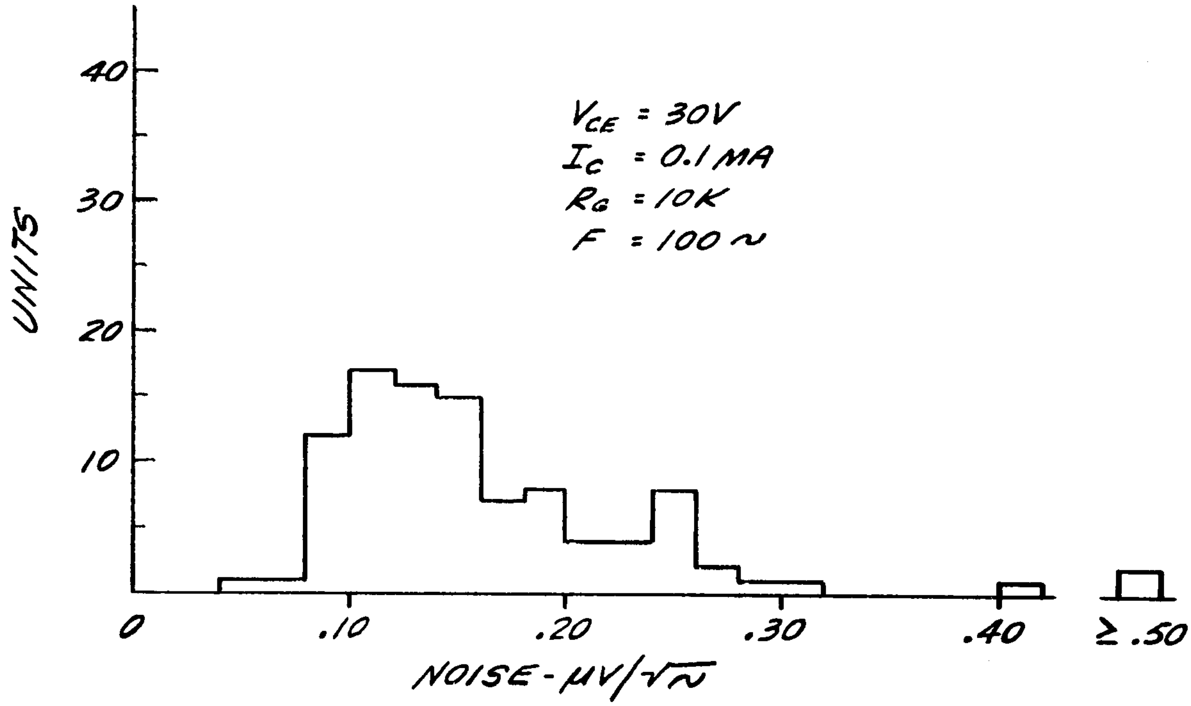


FIGURE 3
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER #III
TEST A



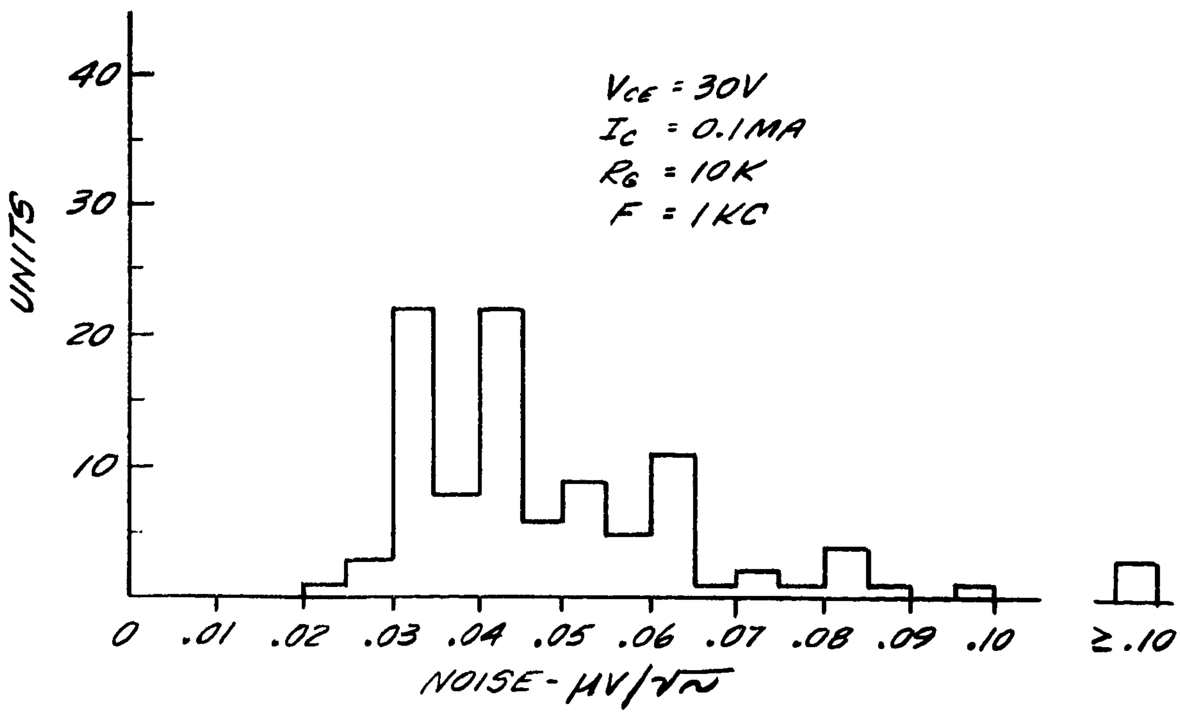
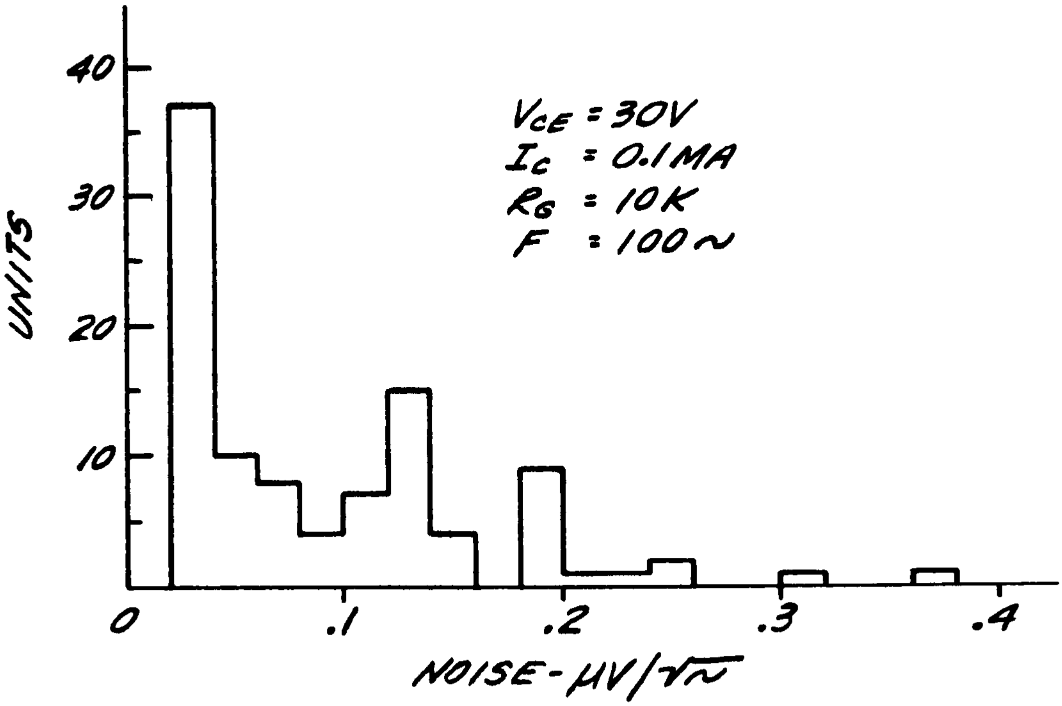


FIGURE 4
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER # IV
TEST A



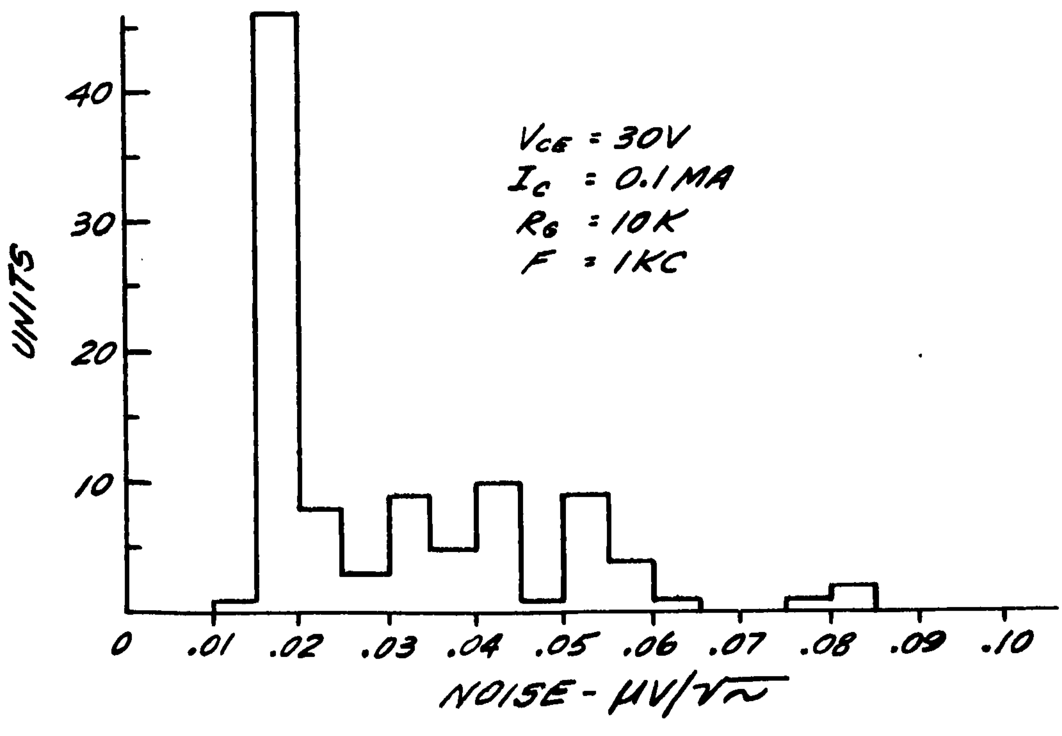
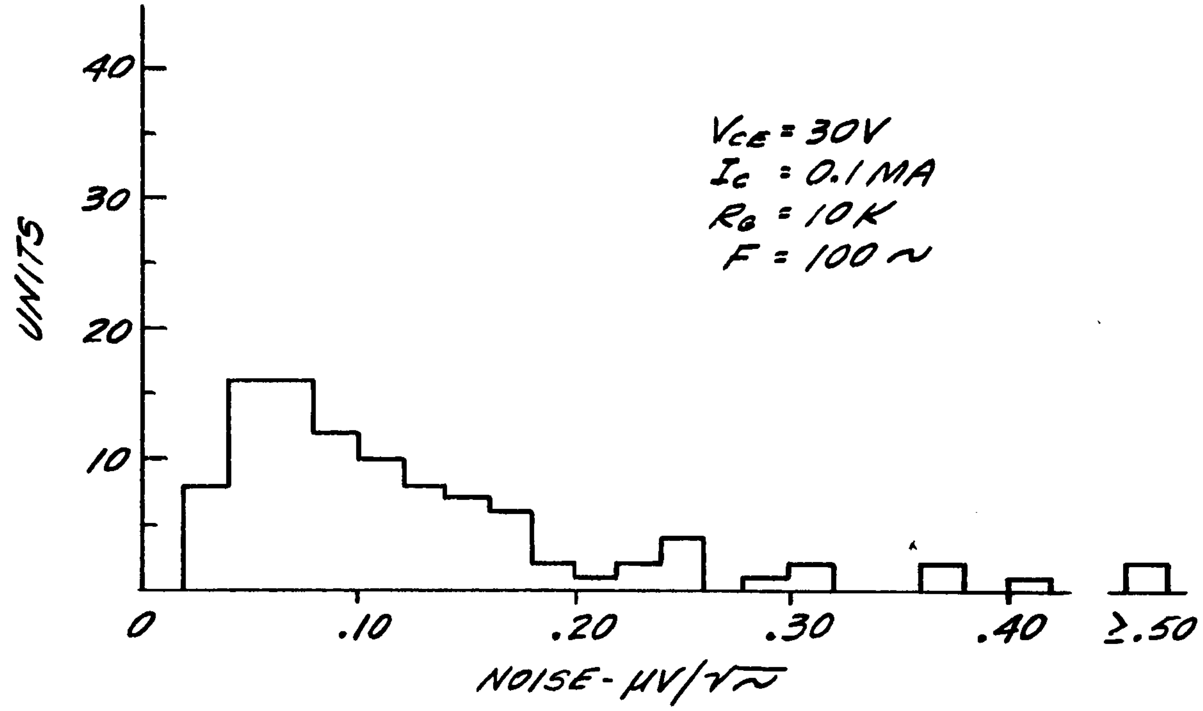


FIGURE 5
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER # V
TEST A



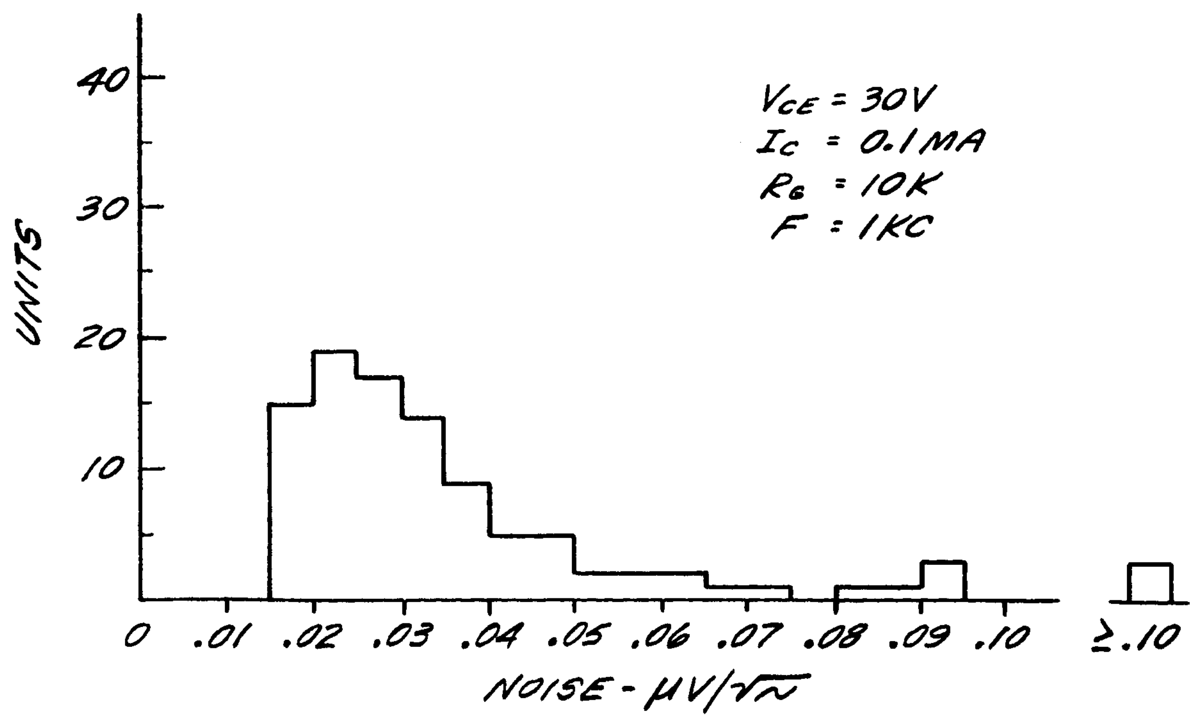
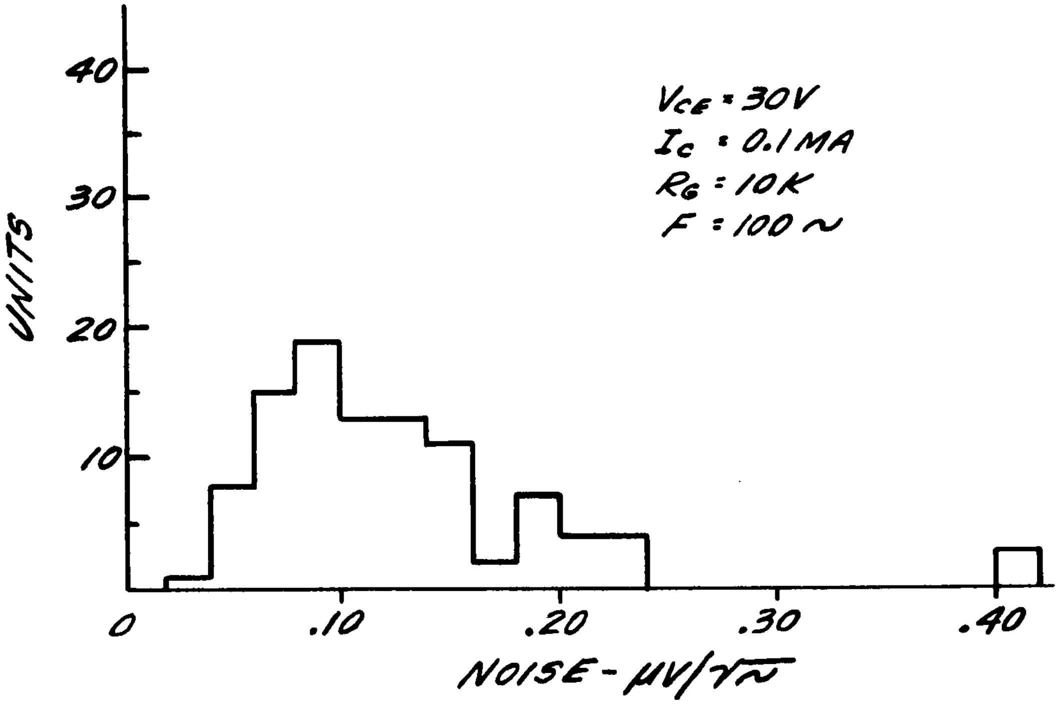


FIGURE 6
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER # VI
TEST A



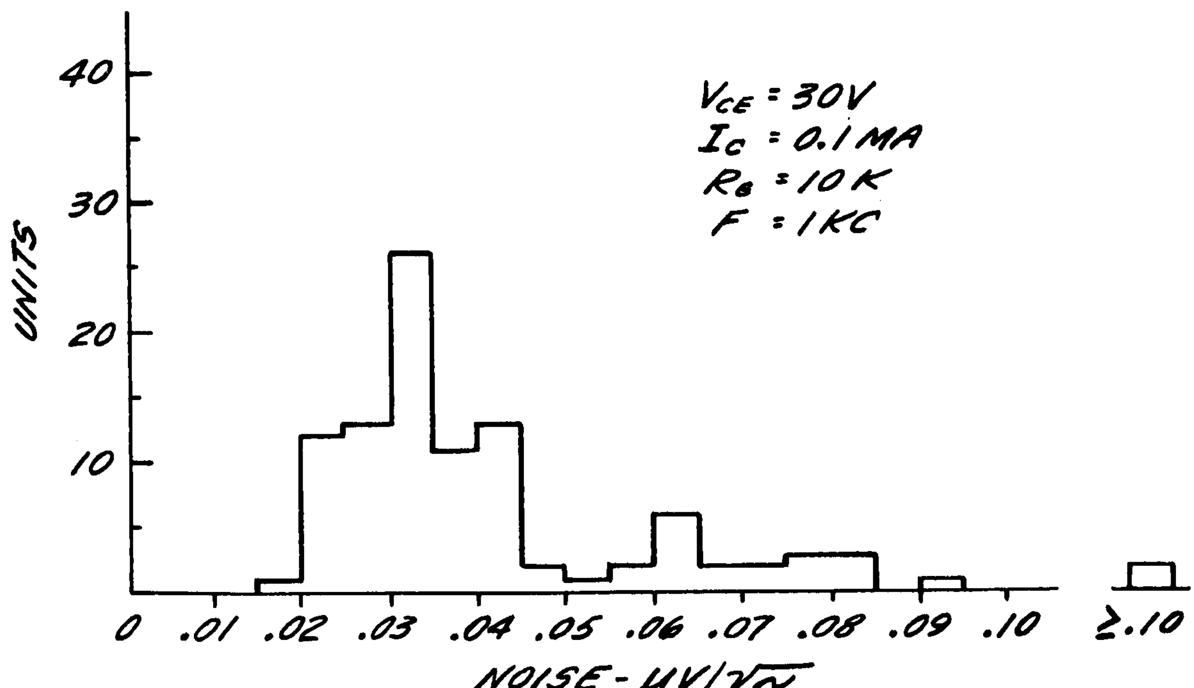
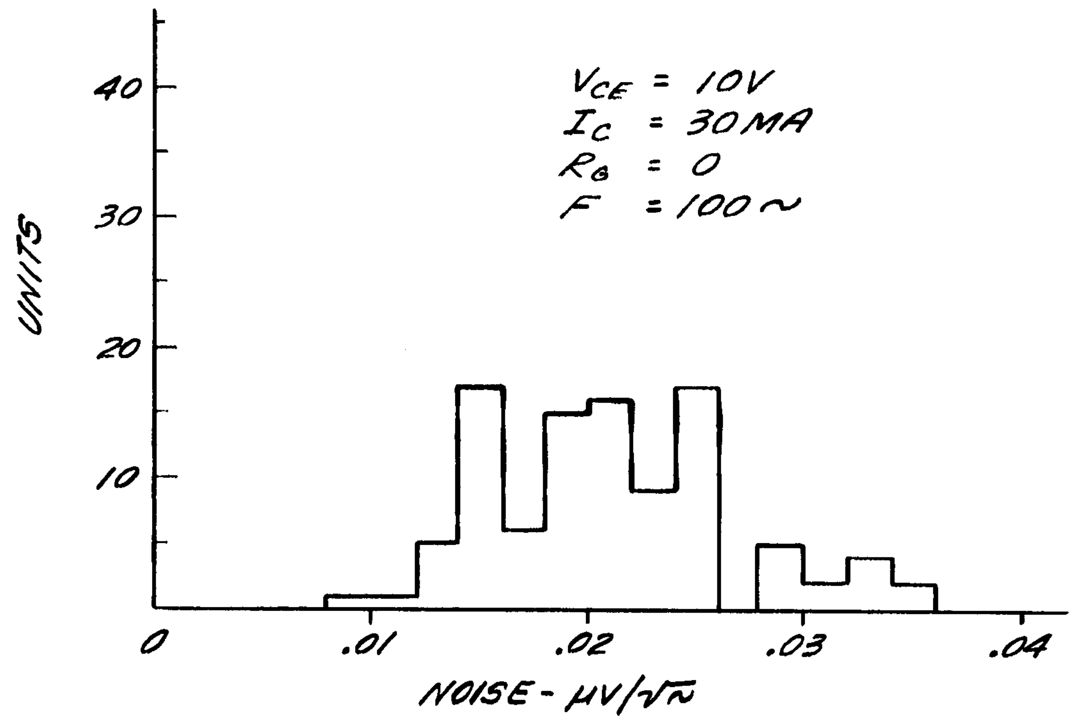


FIGURE 7
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER #I
TEST B



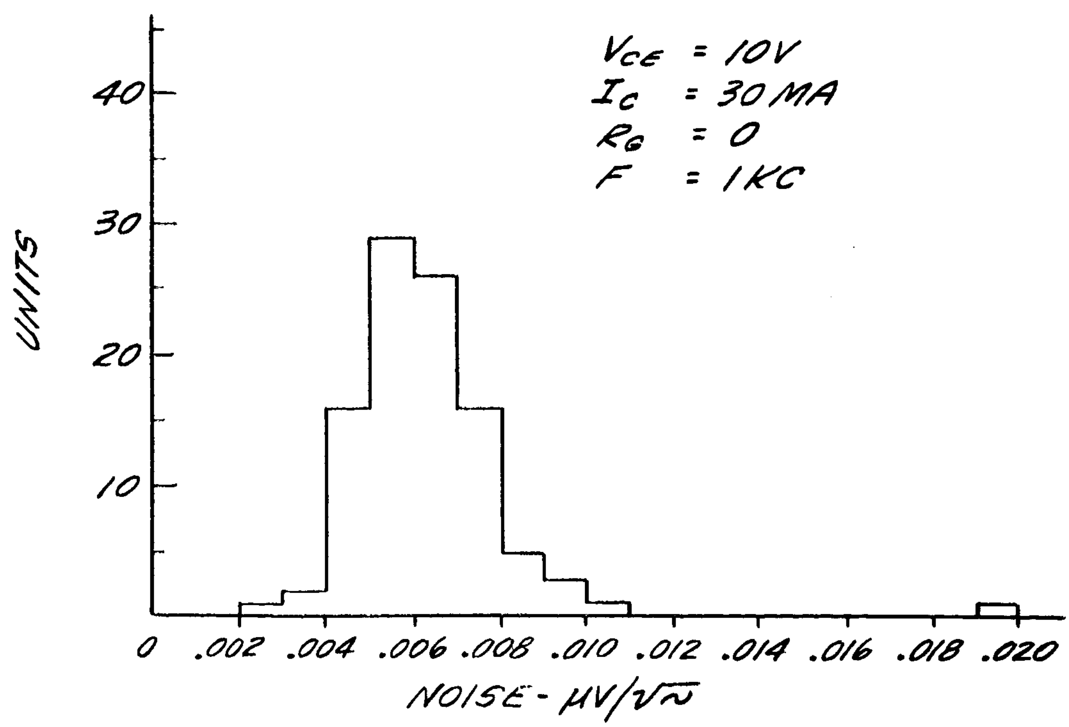
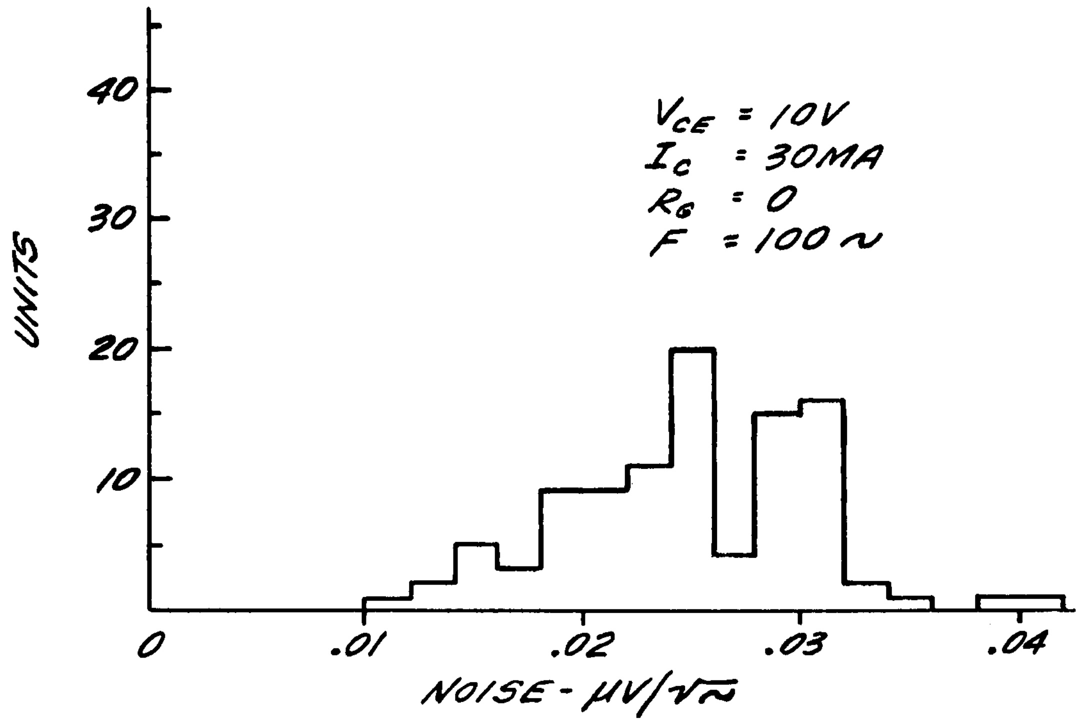


FIGURE 8
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER # II
TEST B



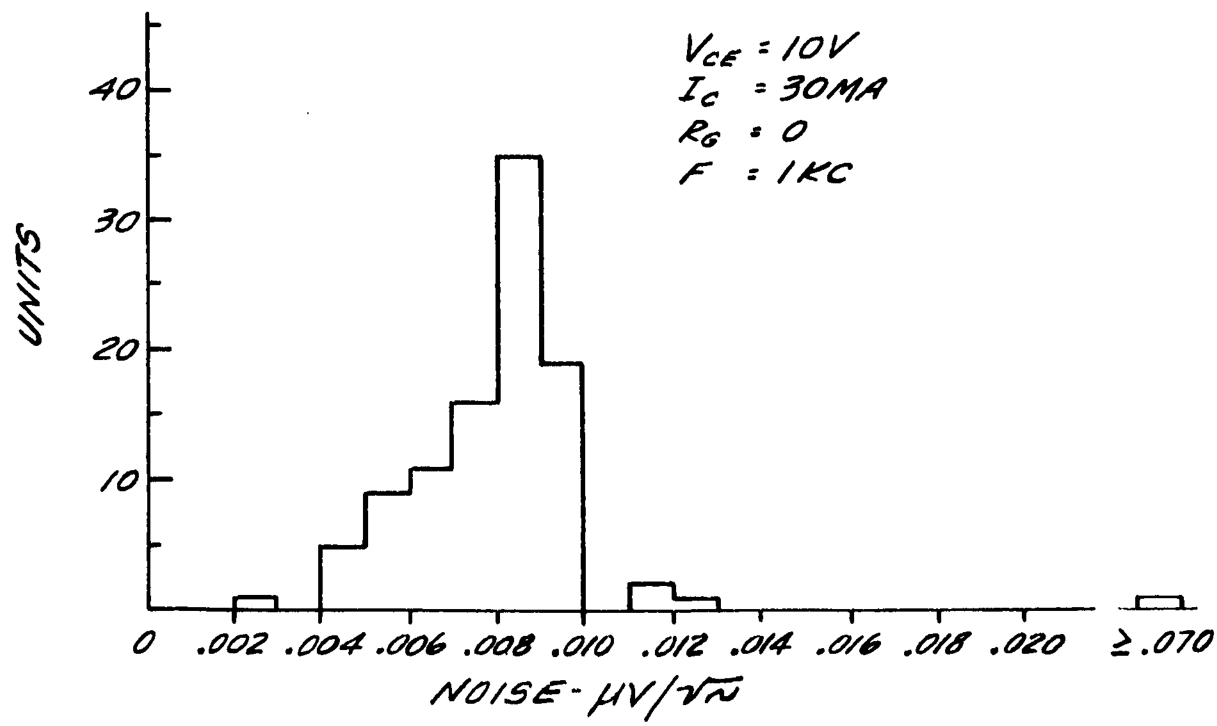
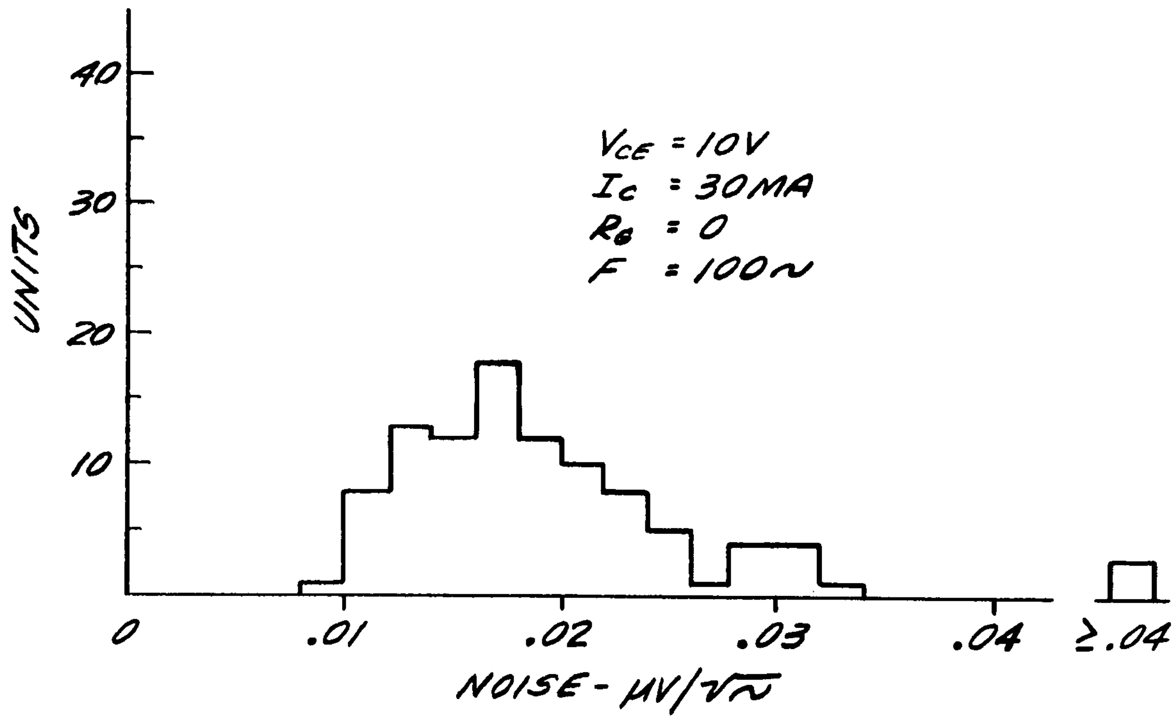


FIGURE 9
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER # III
TEST B



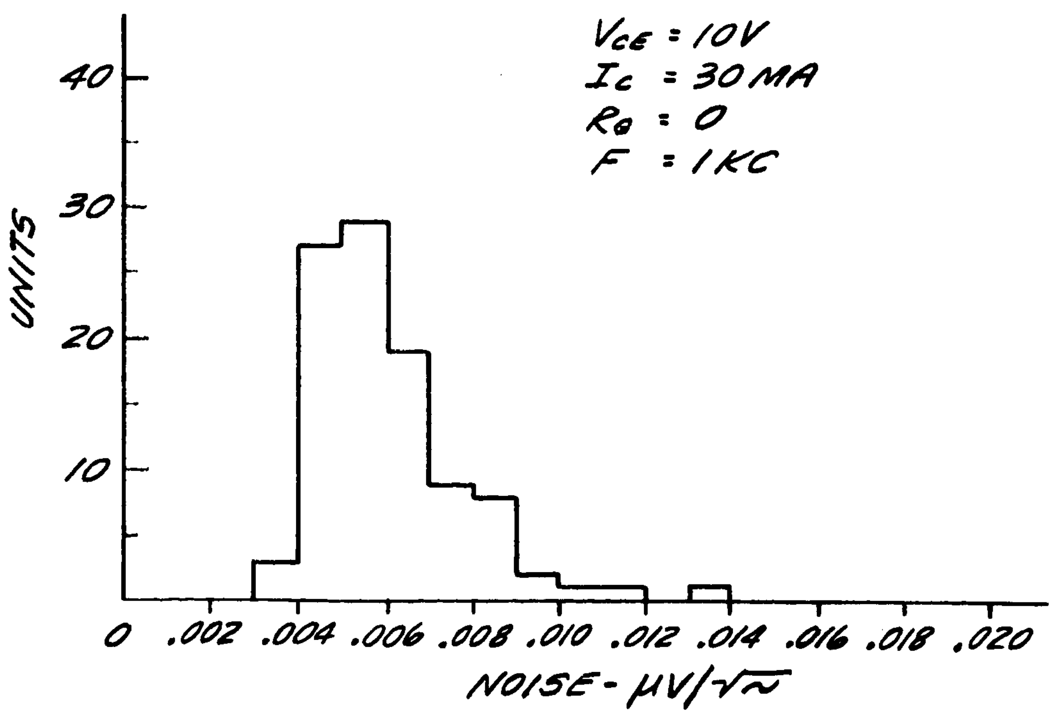
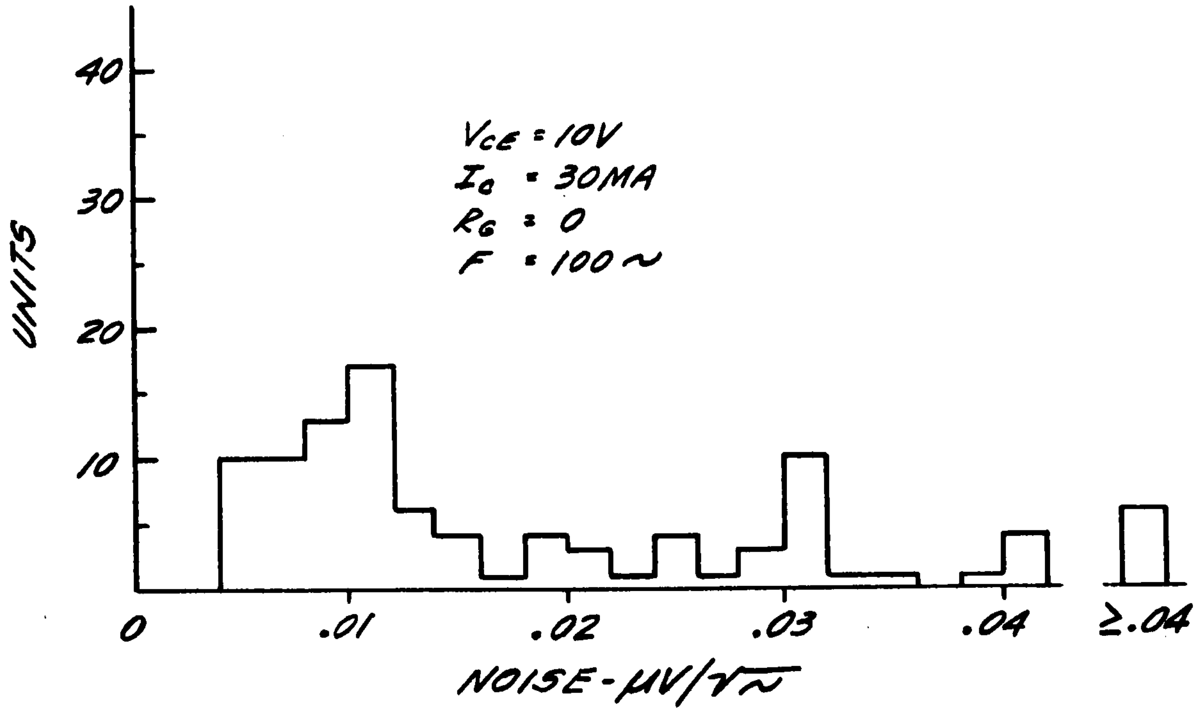


FIGURE 10
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER #IV
TEST B



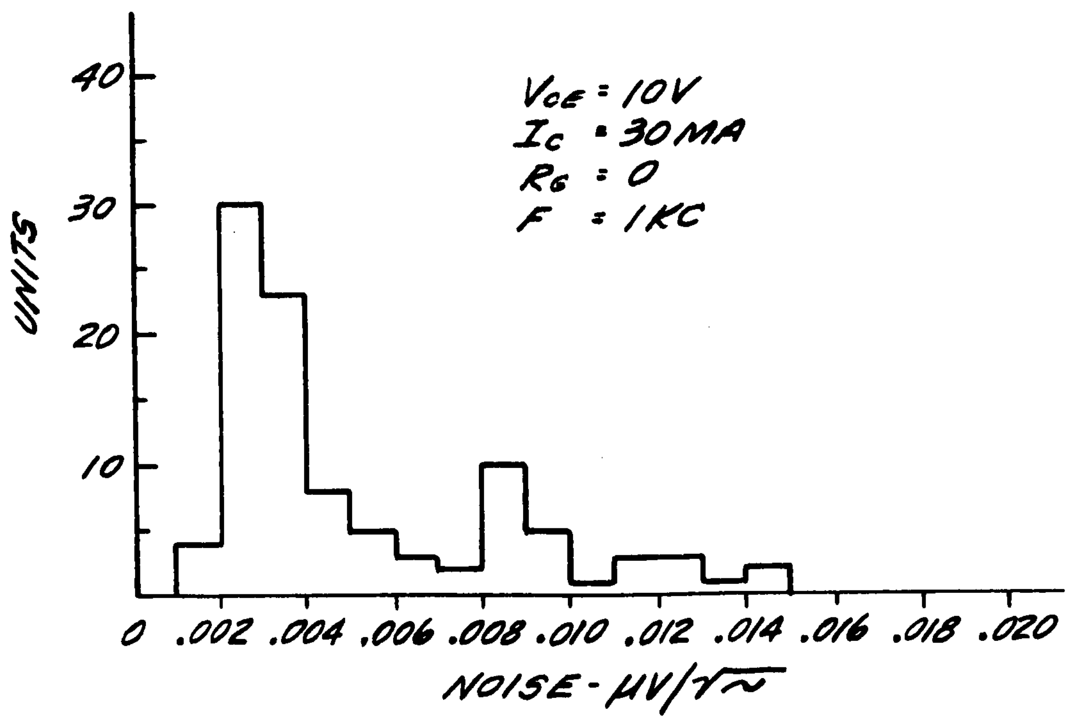
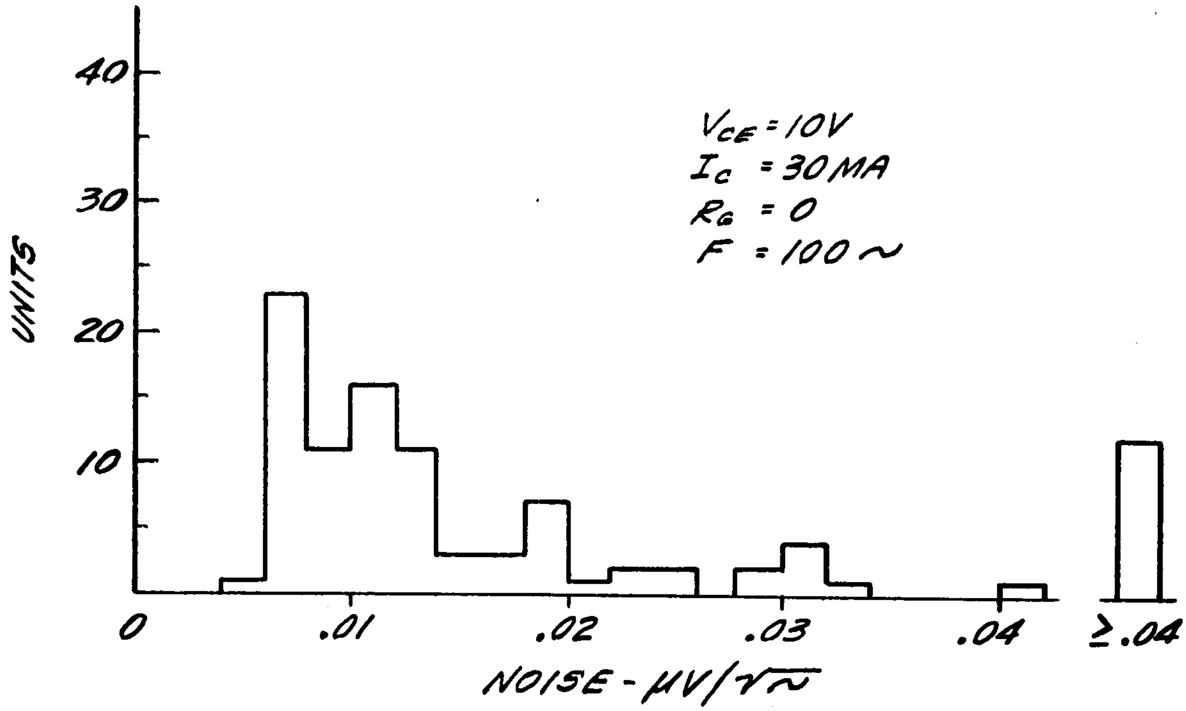


FIGURE 11
HISTOGRAM
100 TRANSISTORS, 2N1613
MANUFACTURER # V
TEST B



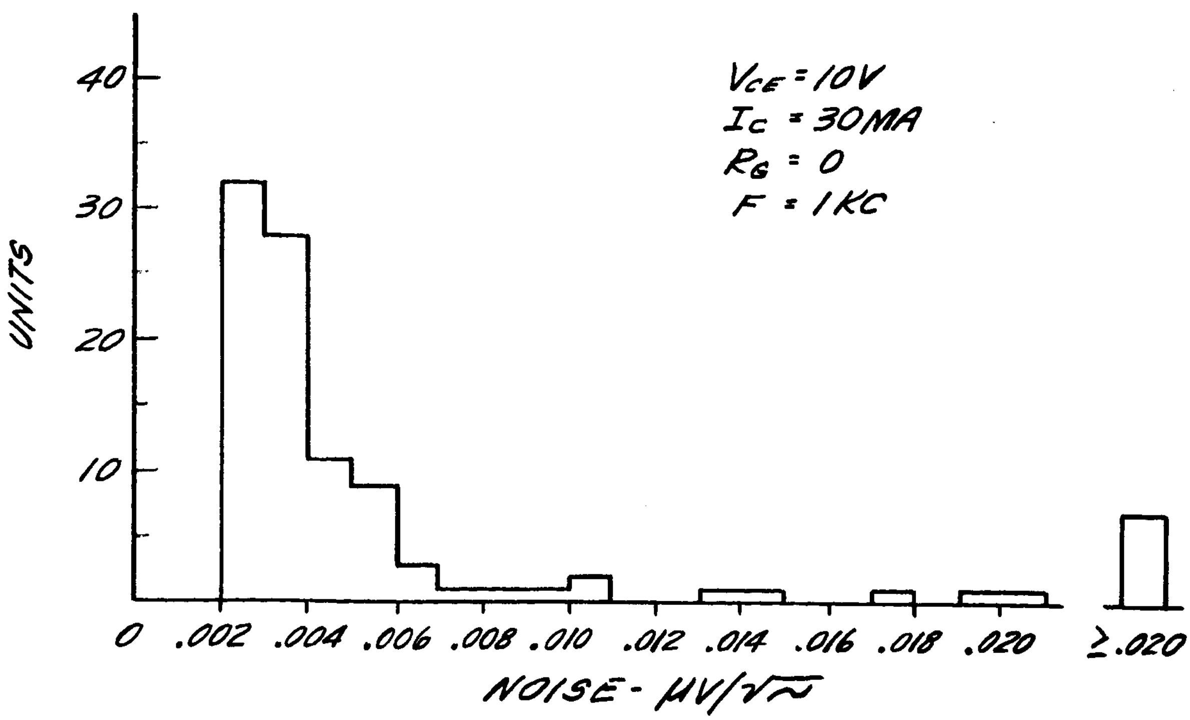
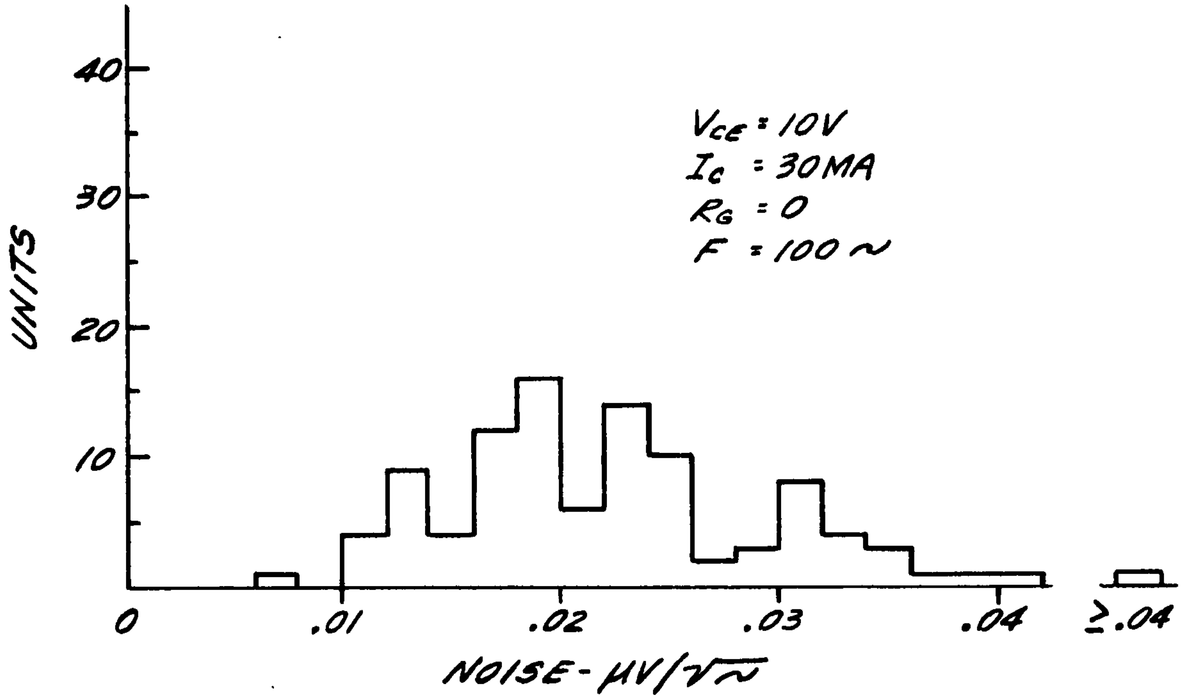


FIGURE 12
HISTOGRAM
100 TRANSISTOR, 2N1613
MANUFACTURER #VI
TEST B



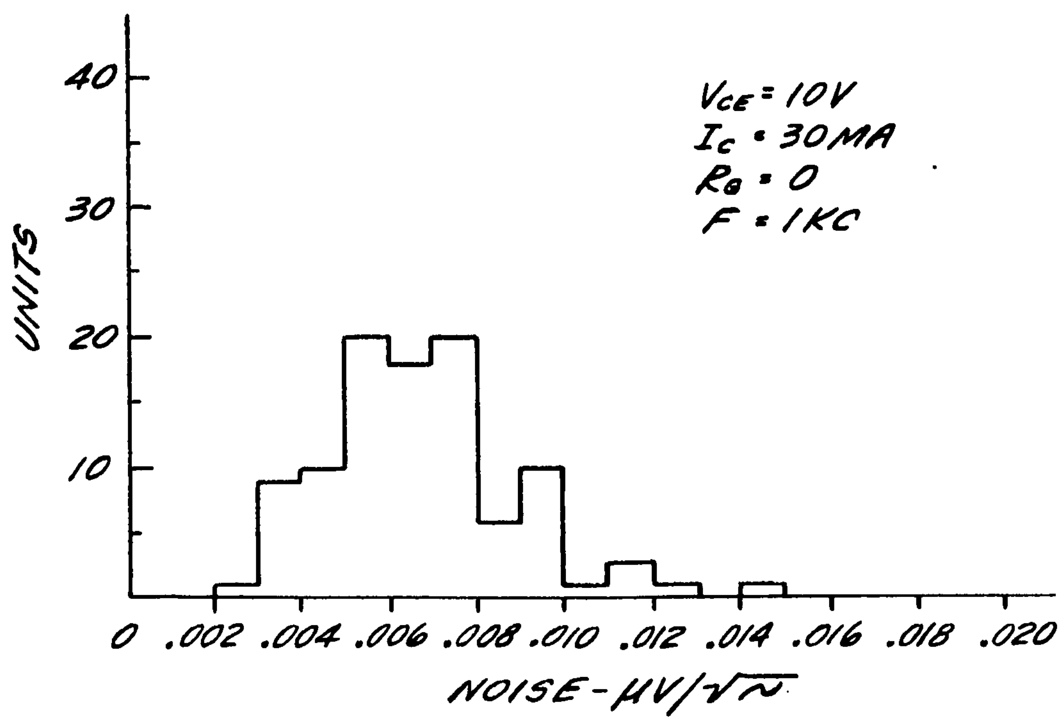
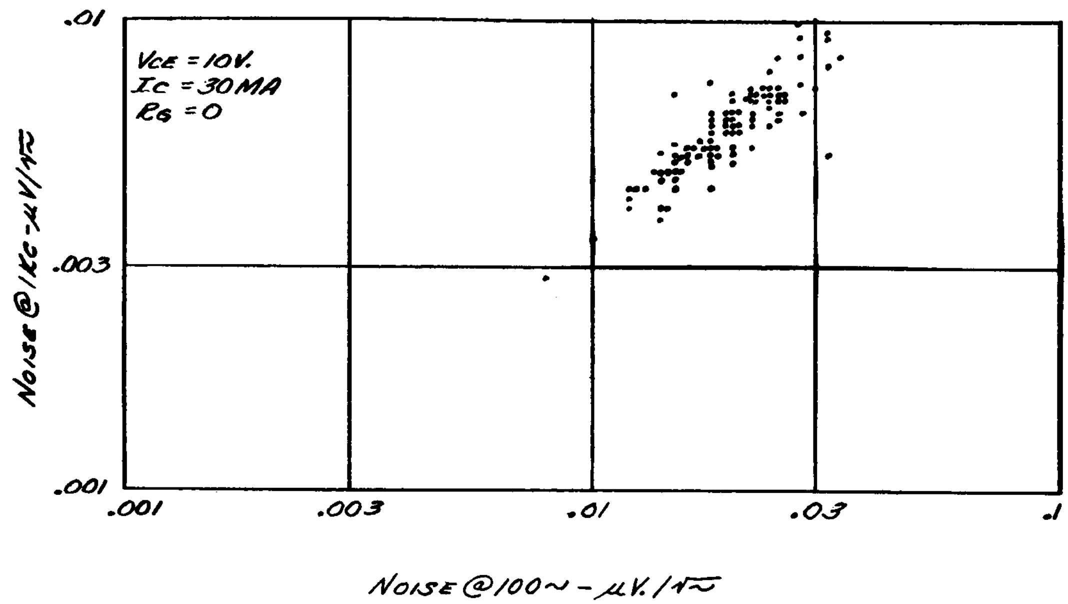


FIGURE 13
SCATTER PLOT
100~ NOISE VS. 1KC NOISE
100 TRANSISTORS 2N1613
MANUFACTURER I



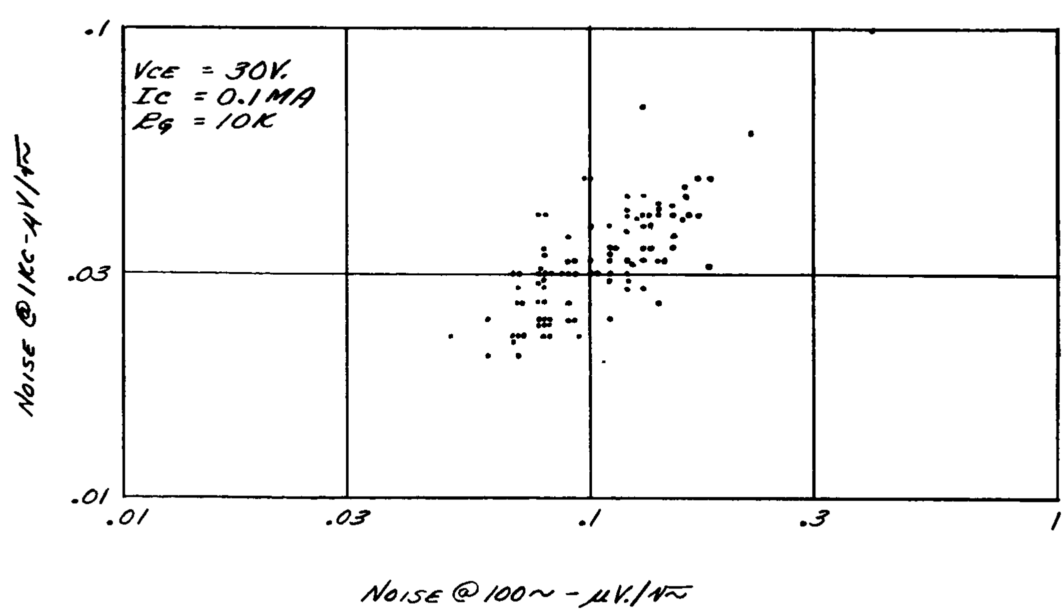
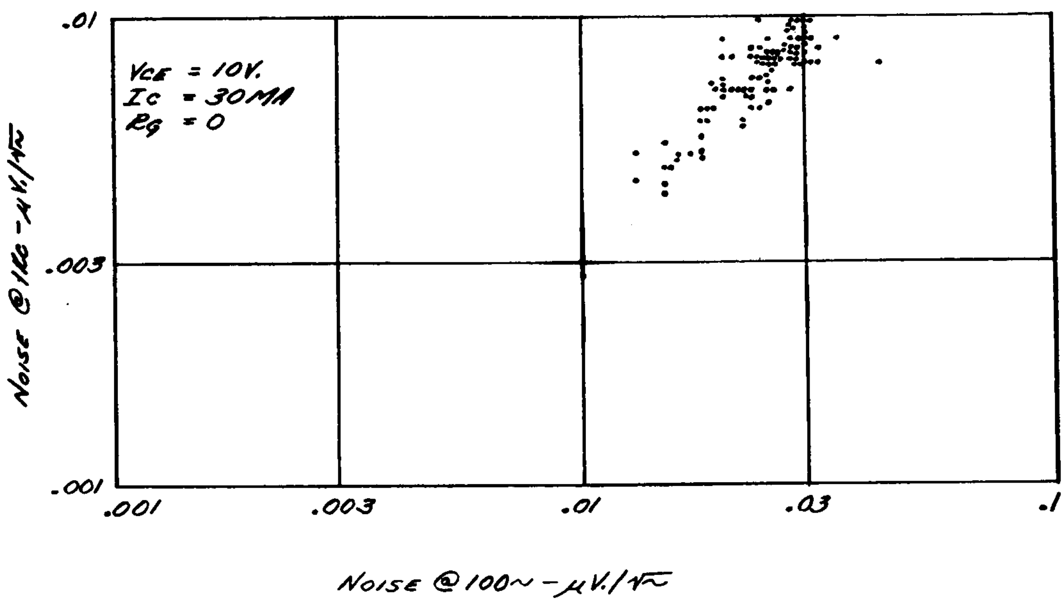


FIGURE 14
SCATTER PLOT
100~ NOISE VS. 1 KC NOISE
100 TRANSISTORS 2N1613
MANUFACTURER II



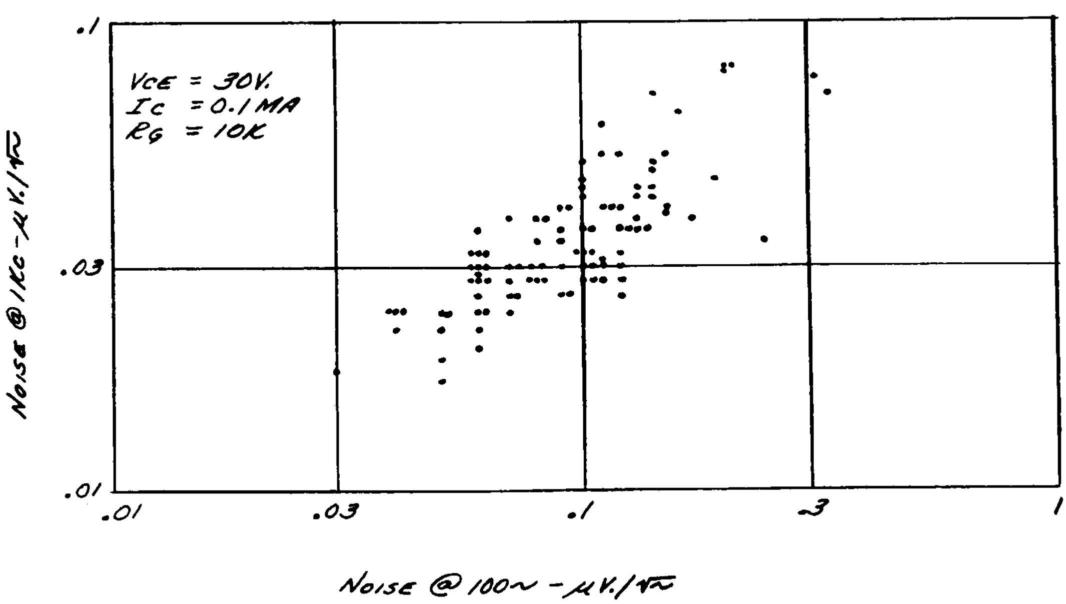
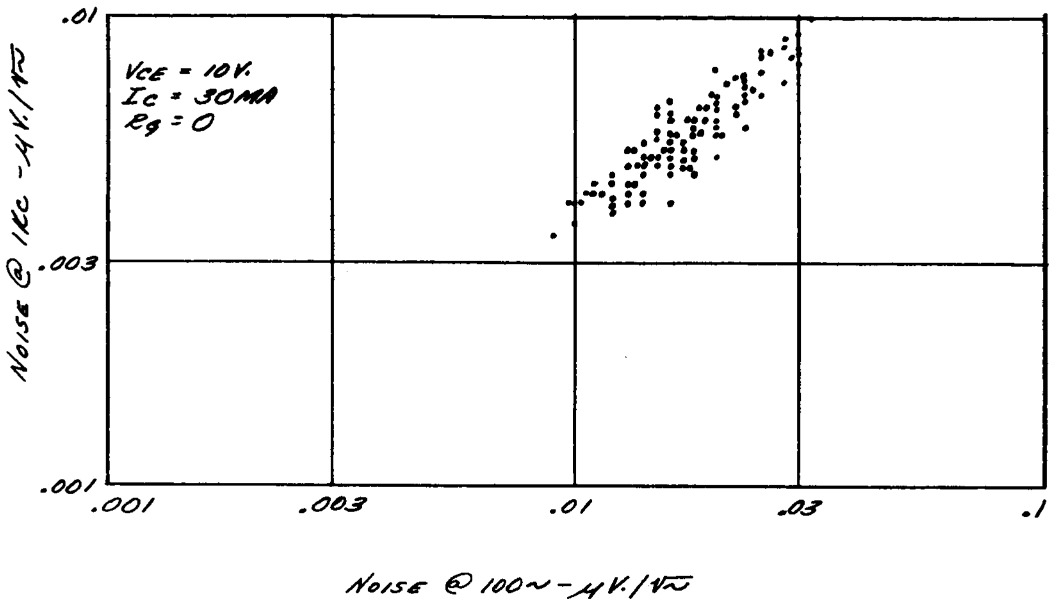


FIGURE 15
SCATTER PLOT
100~ NOISE VS. 1KC NOISE
100 TRANSISTORS 2N1613
MANUFACTURER III



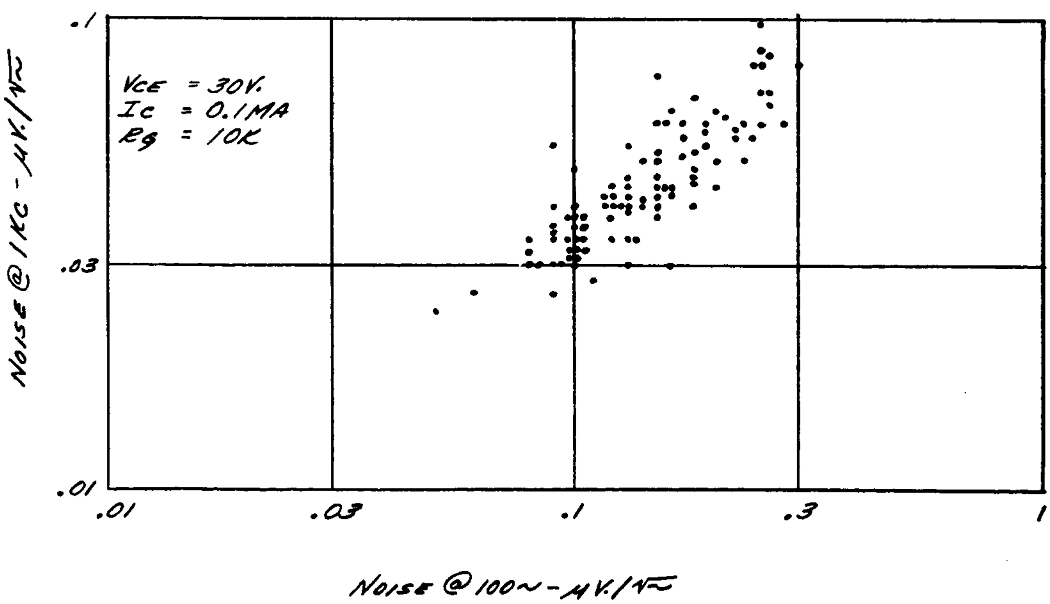
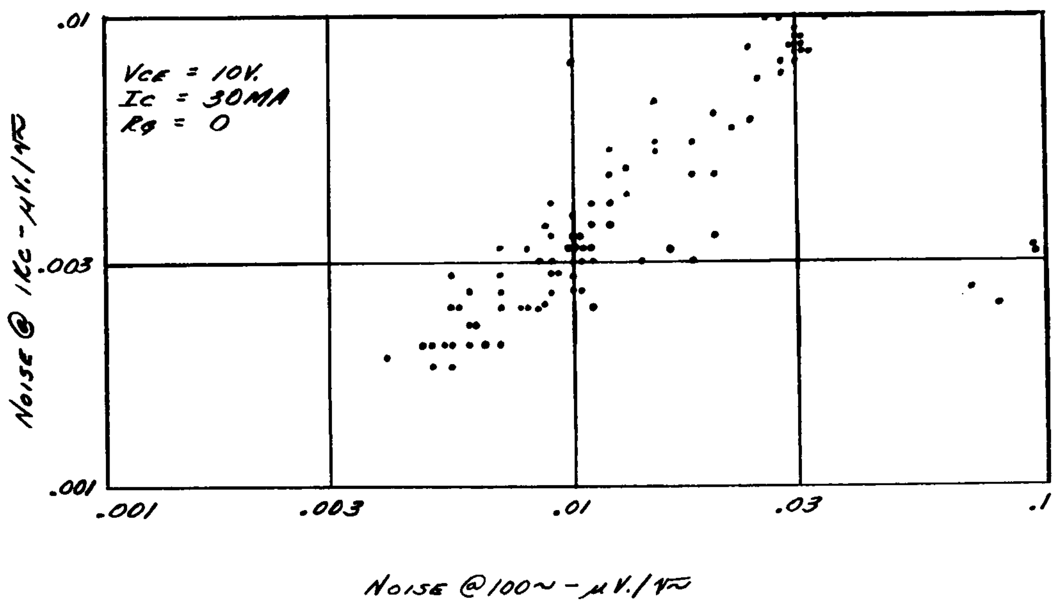


FIGURE 16
SCATTER PLOT
100~ NOISE VS. 1Kc NOISE
100 TRANSISTORS 2N1613
MANUFACTURER IV



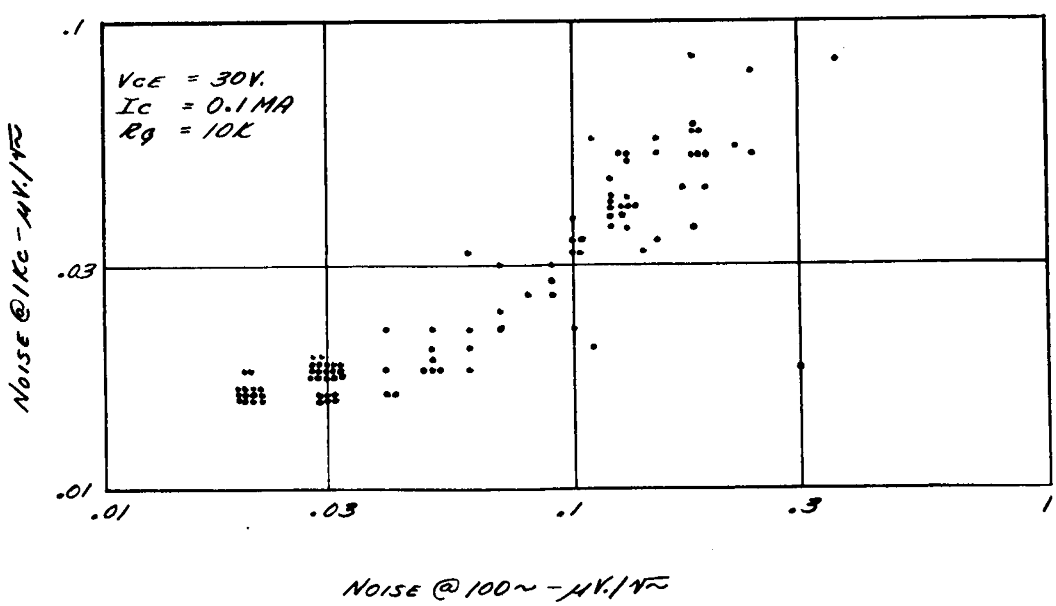
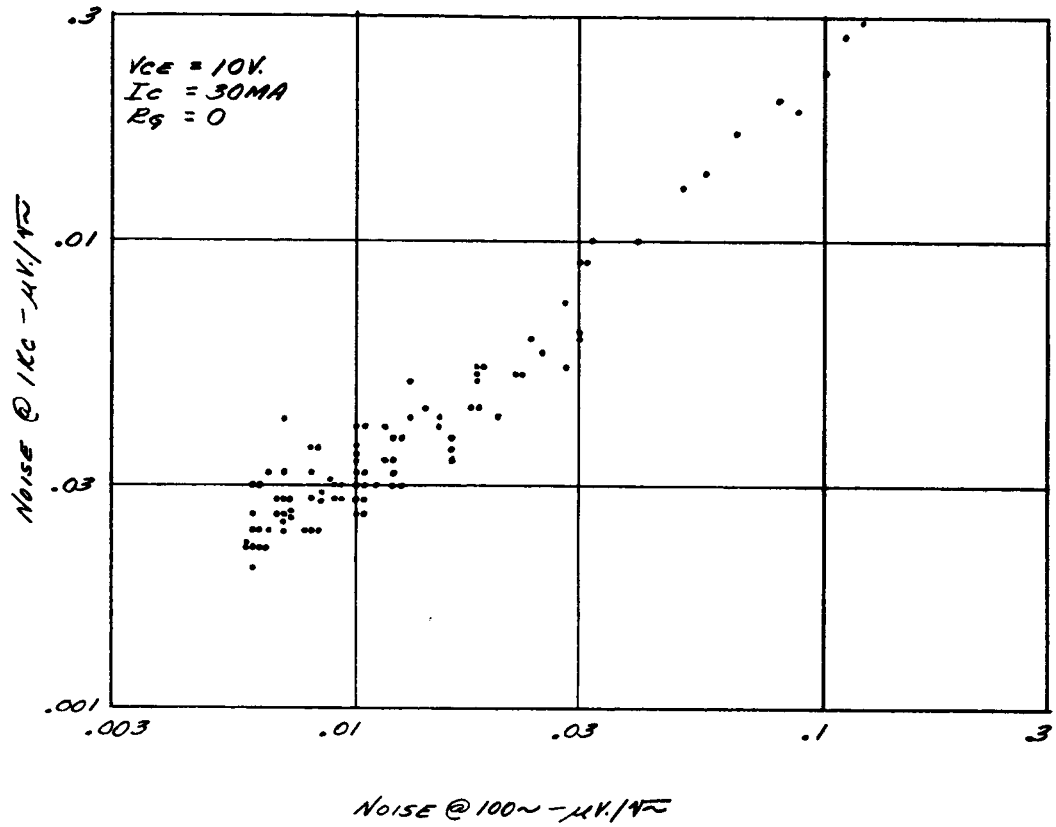


FIGURE 17
SCATTER PLOT
100 ~ NOISE VS. 1 KC NOISE
100 TRANSISTORS 2N1613
MANUFACTURER V



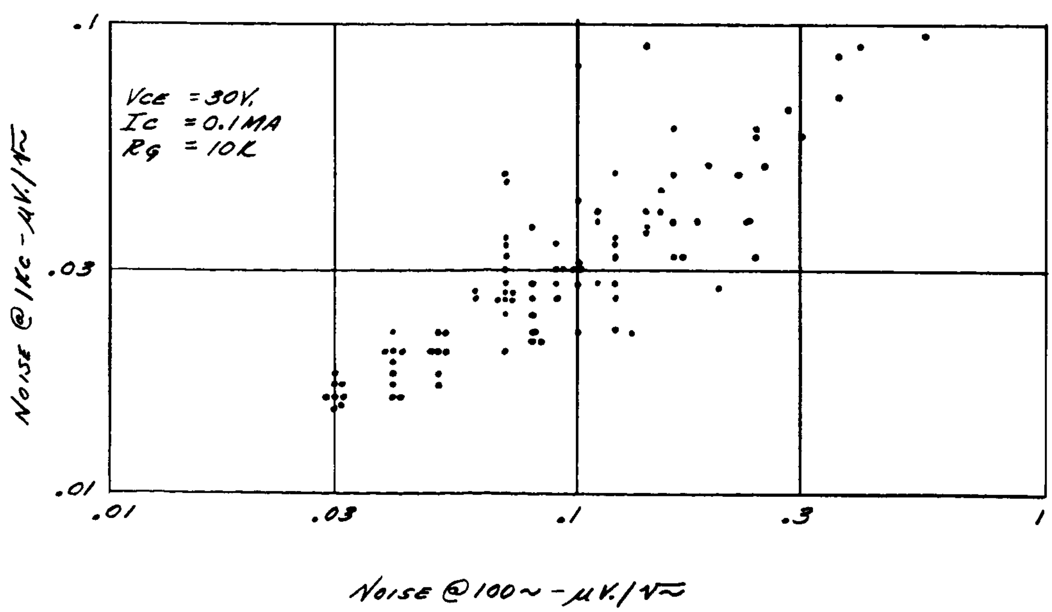
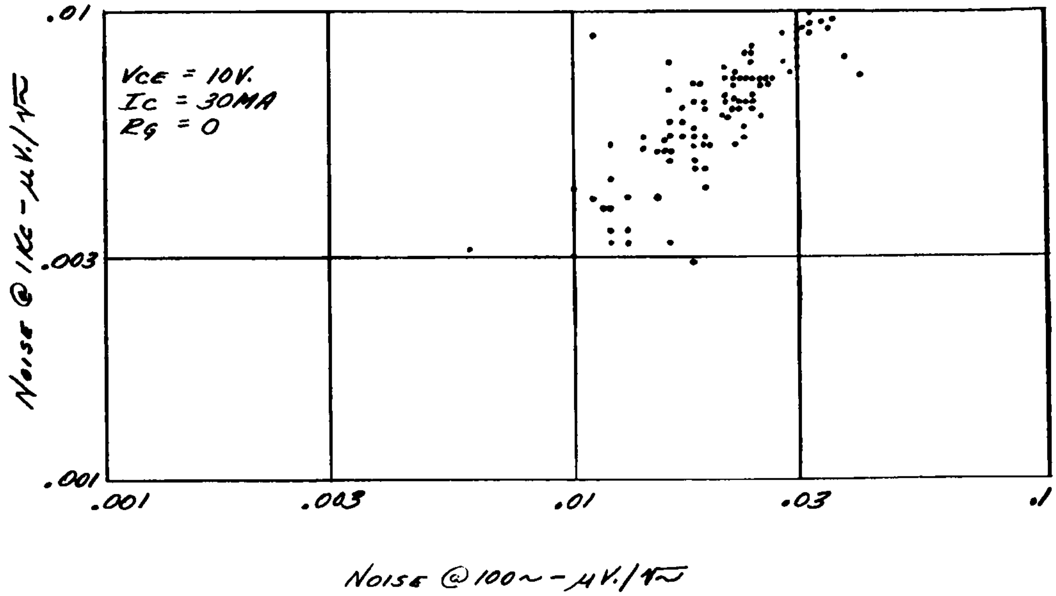


FIGURE 18
SCATTER PLOT
100~ NOISE VS. 1Kc NOISE
100 TRANSISTORS 2N1613
MANUFACTURER VI



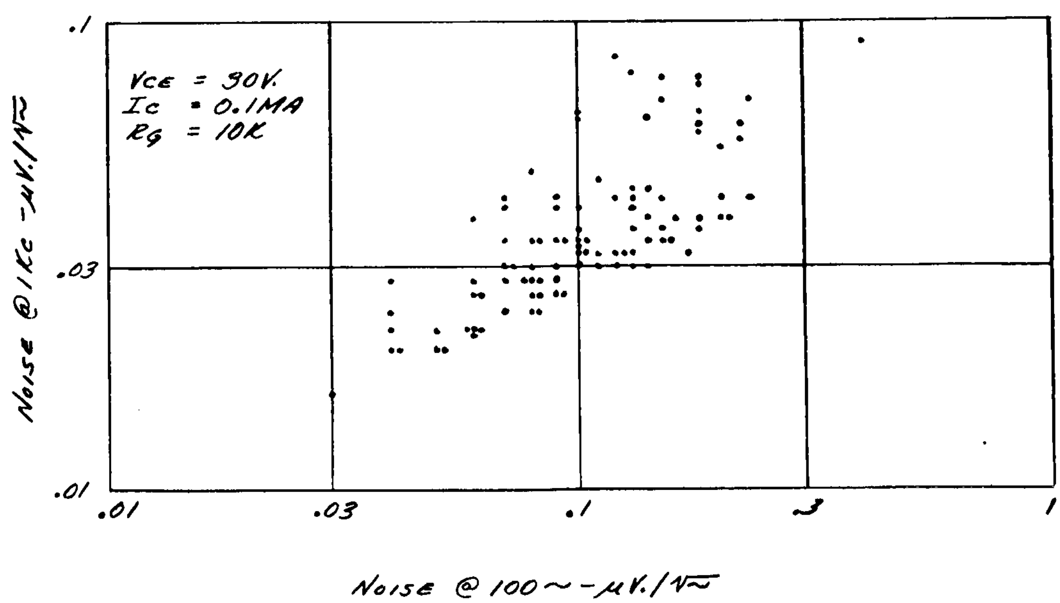
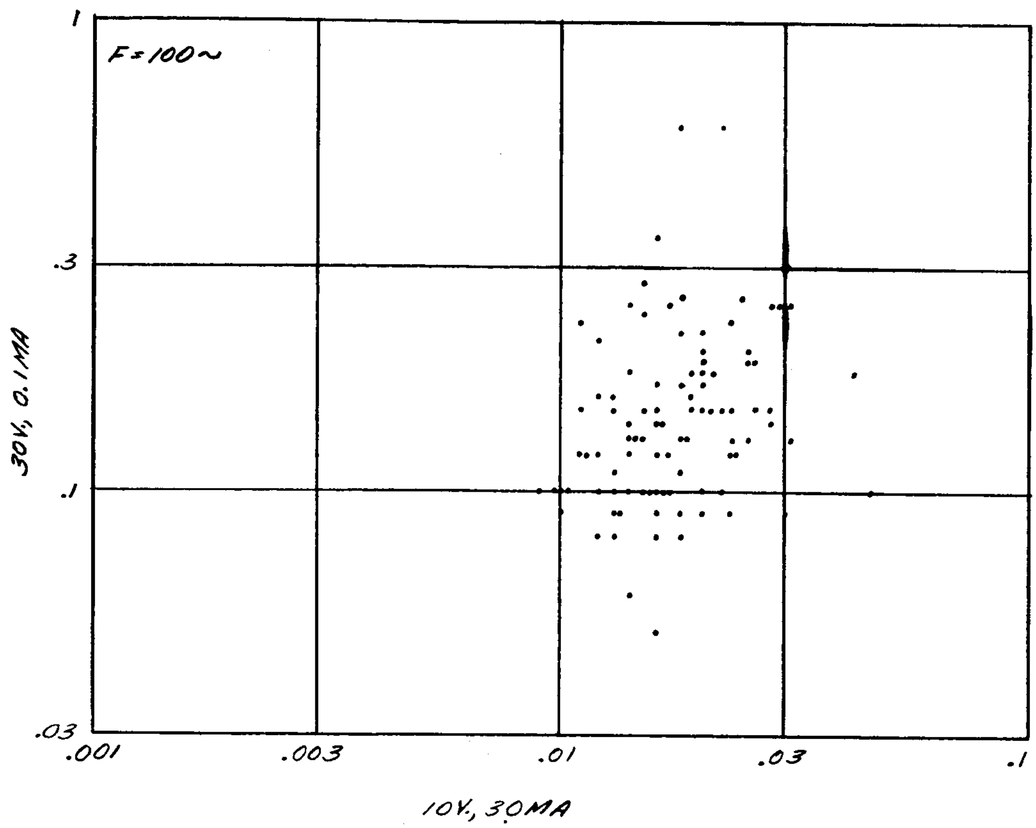
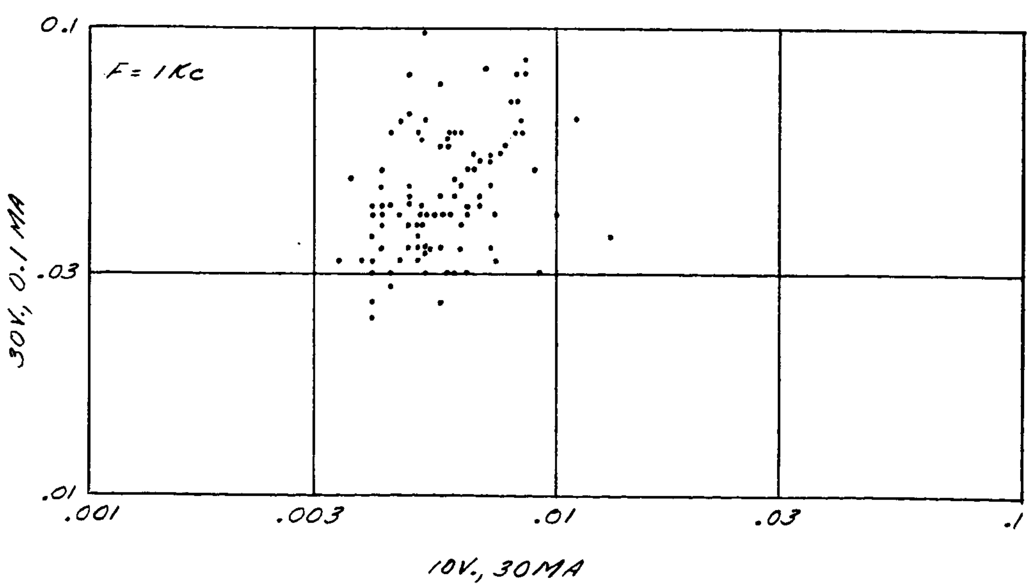


FIGURE 19
SCATTER PLOT

100 TRANSISTORS 2N1613
MANUFACTURER III
TEST A VS. TEST B





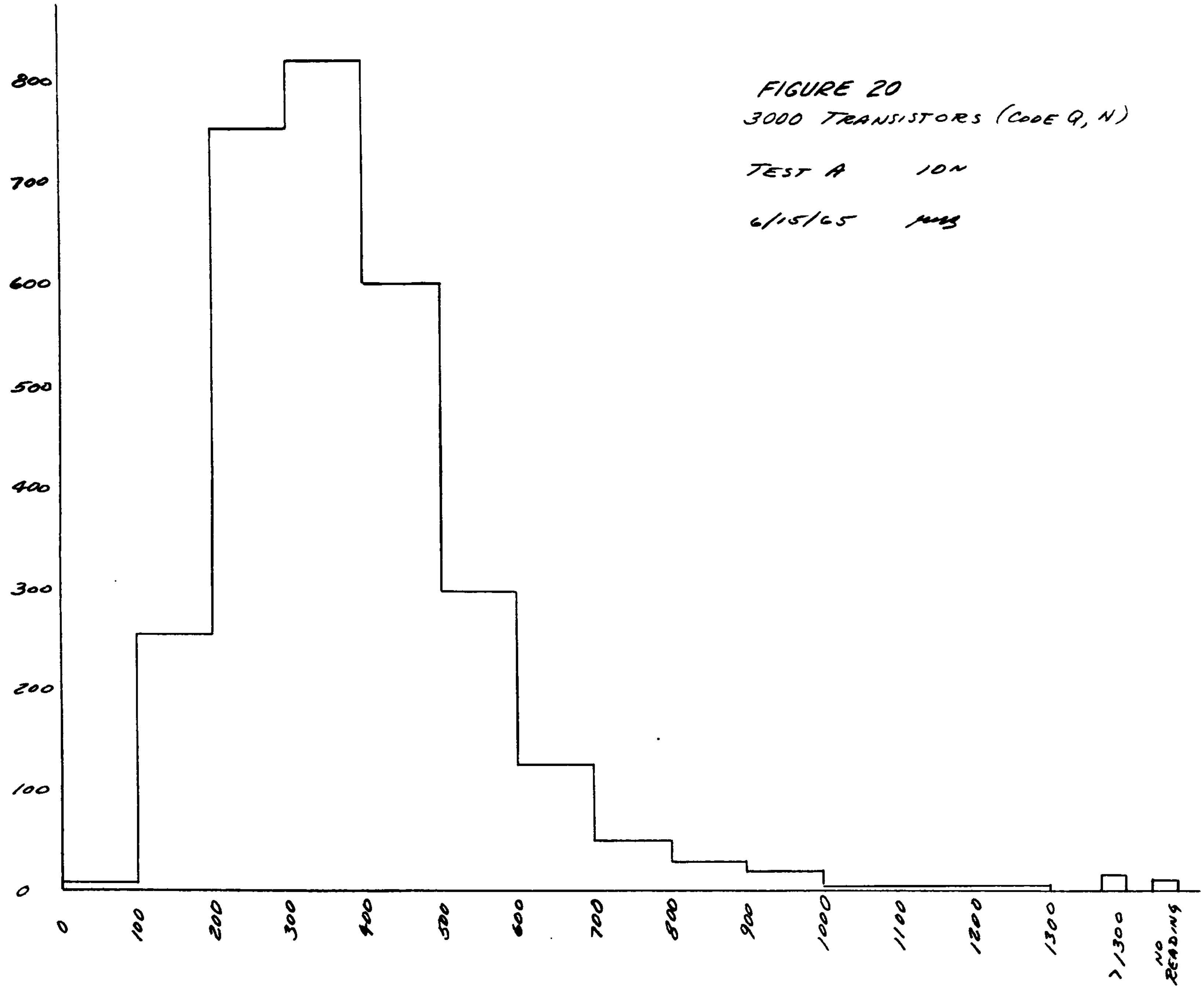


FIGURE 20
3000 TRANSISTORS (CODE Q, N)
TEST A 10N
6/15/65
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
>1300
NO READING

FIGURE 21

1300 TRANSISTORS (CODE N)

TEST A 10 ~

6/15/65

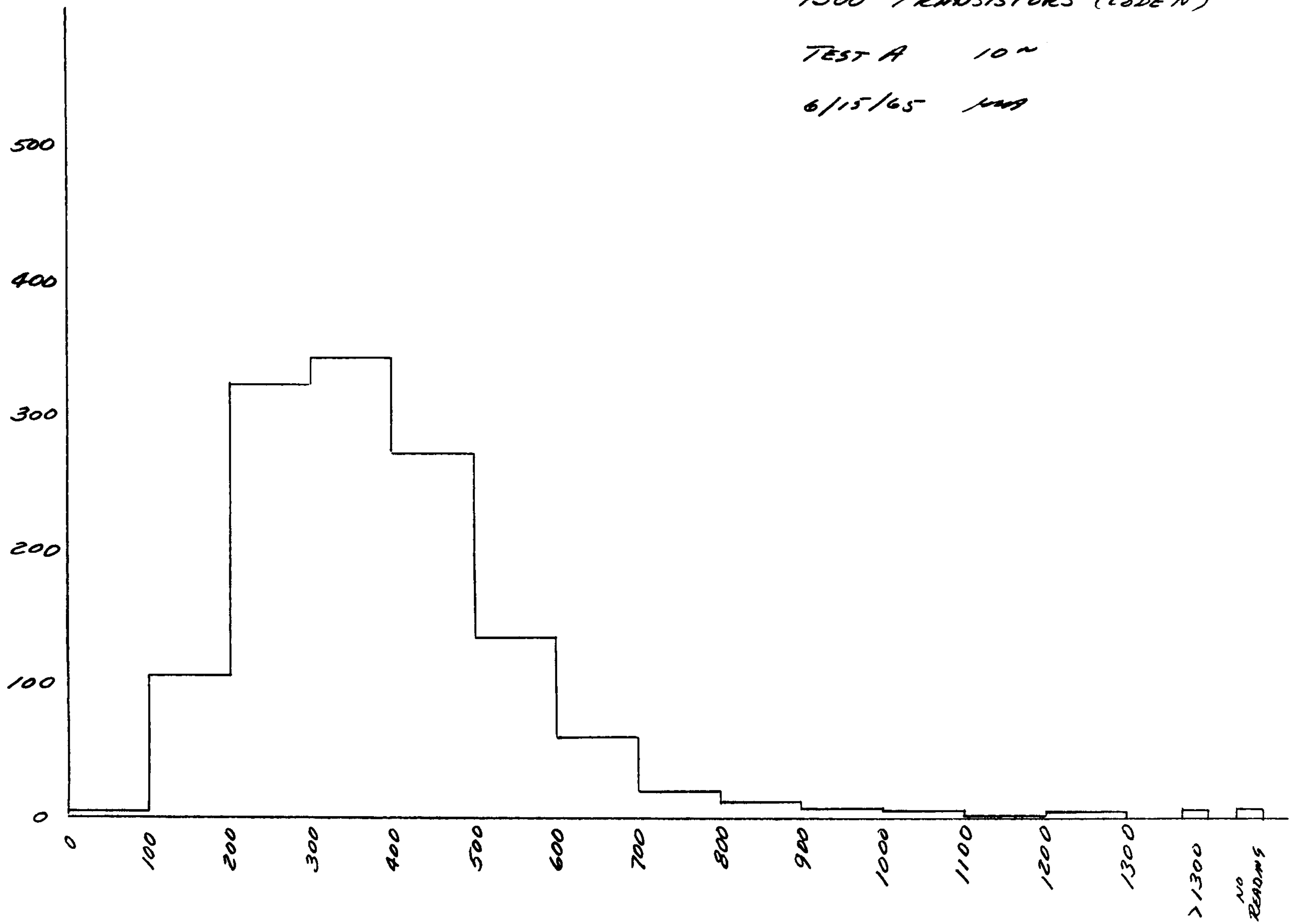
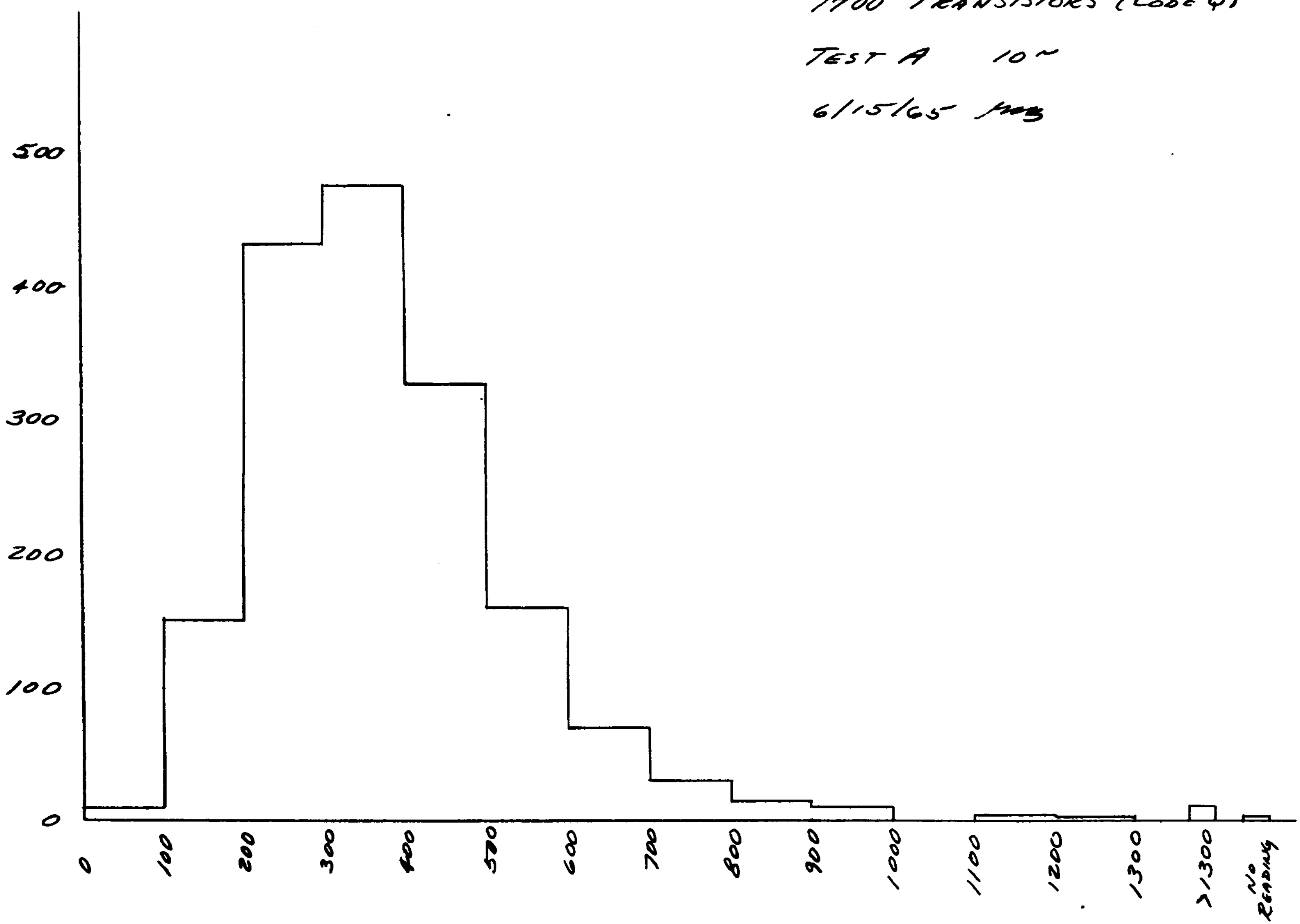


FIGURE 22

1700 TRANSISTORS (CODE Q)

TEST A 10~

6/15/65



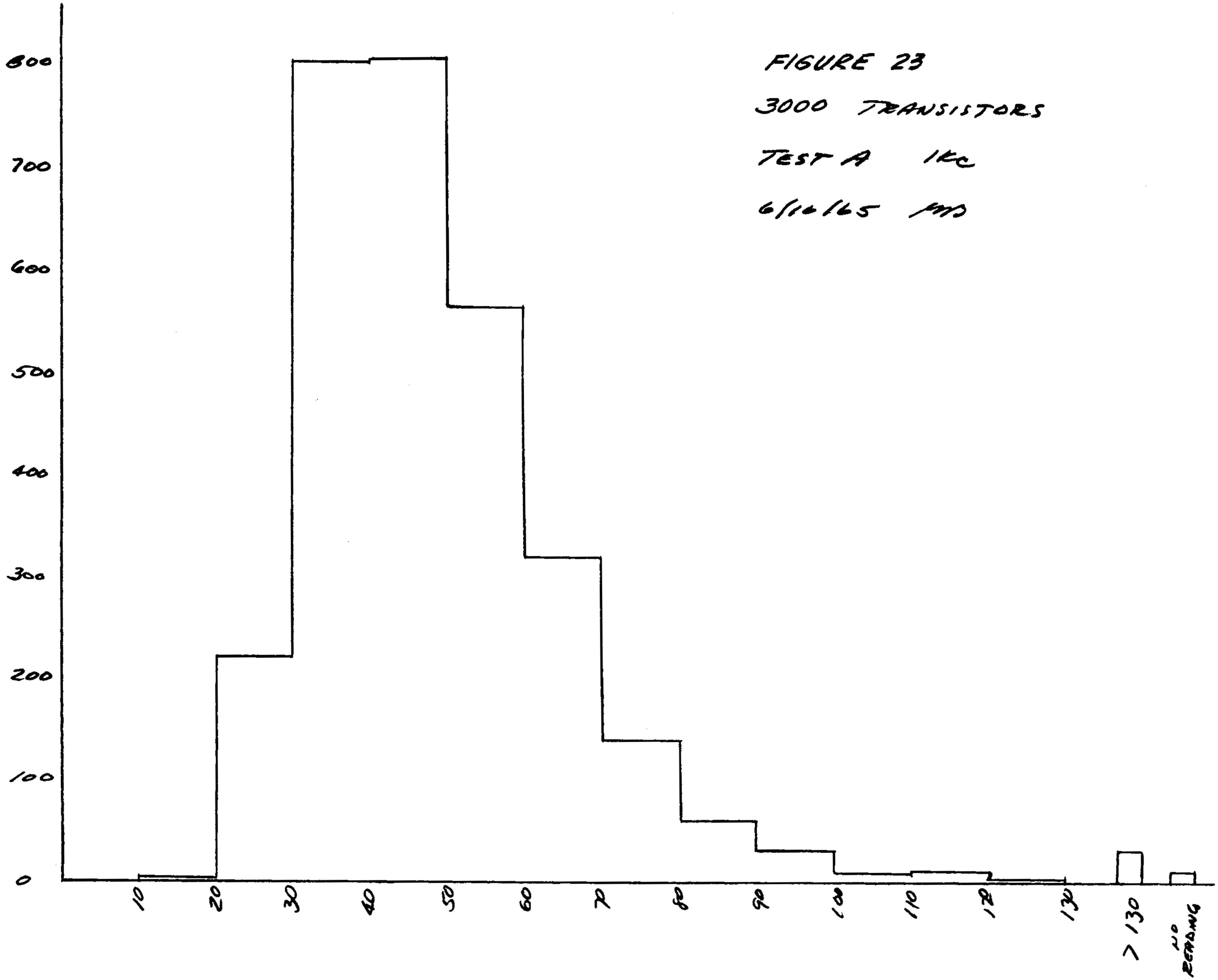


FIGURE 23

3000 TRANSISTORS

TEST A 1KC

6/16/65 MD

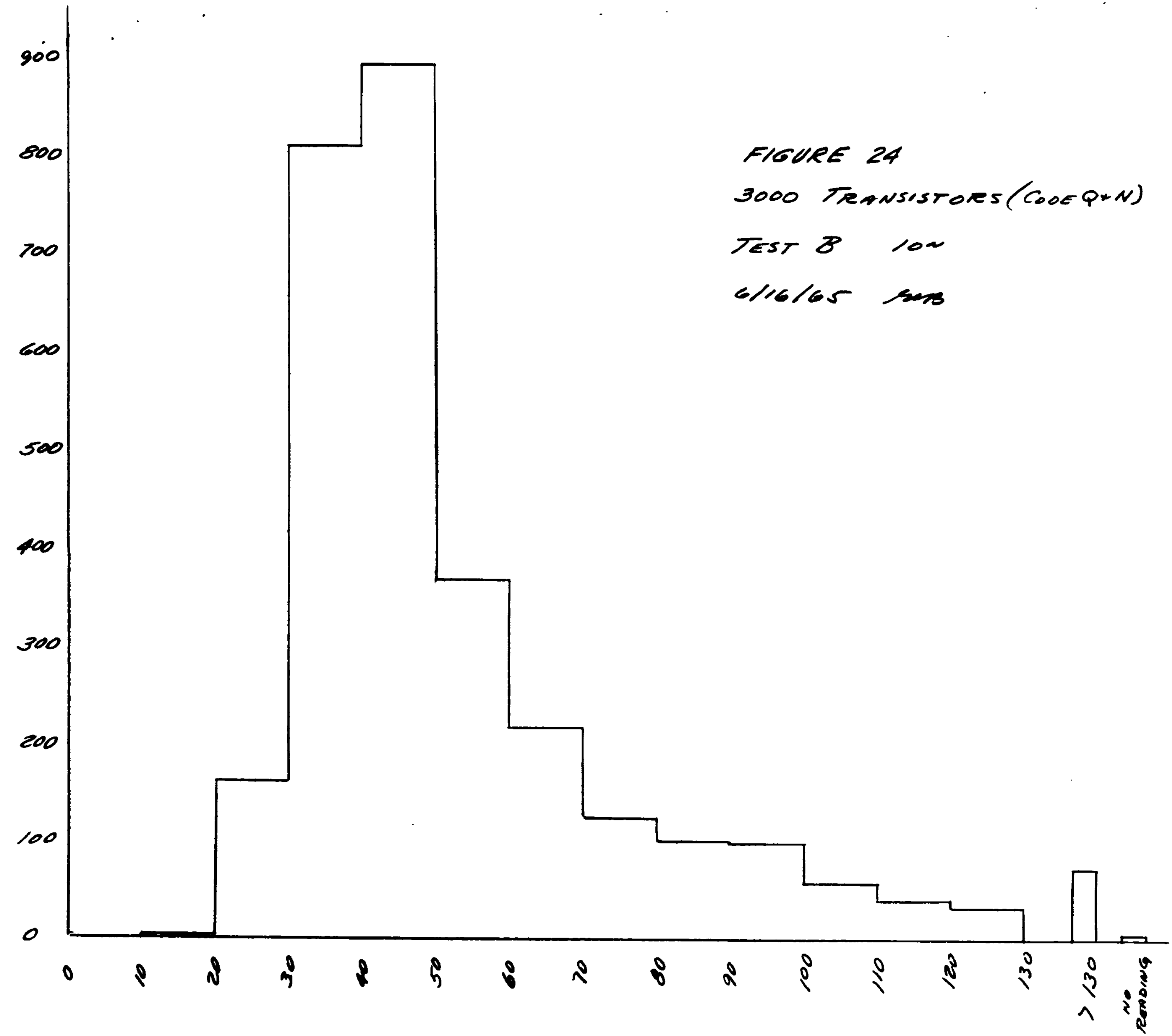


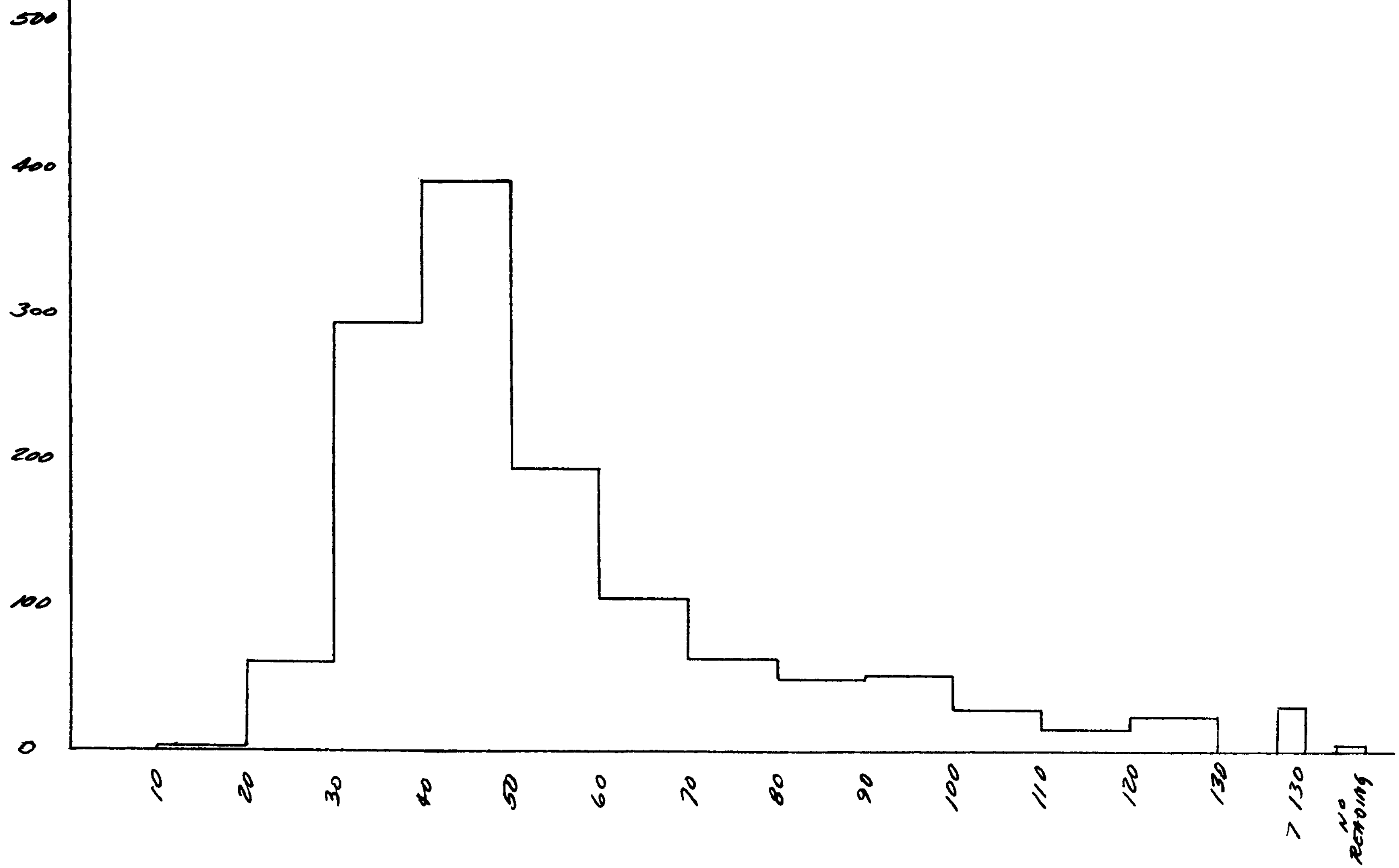
FIGURE 24
3000 TRANSISTORS (CODE Q+N)
TEST B 10Ω
6/16/65

FIGURE 25

1300 TRANSISTORS (CODE N)

TEST 73 10N

6/16/65



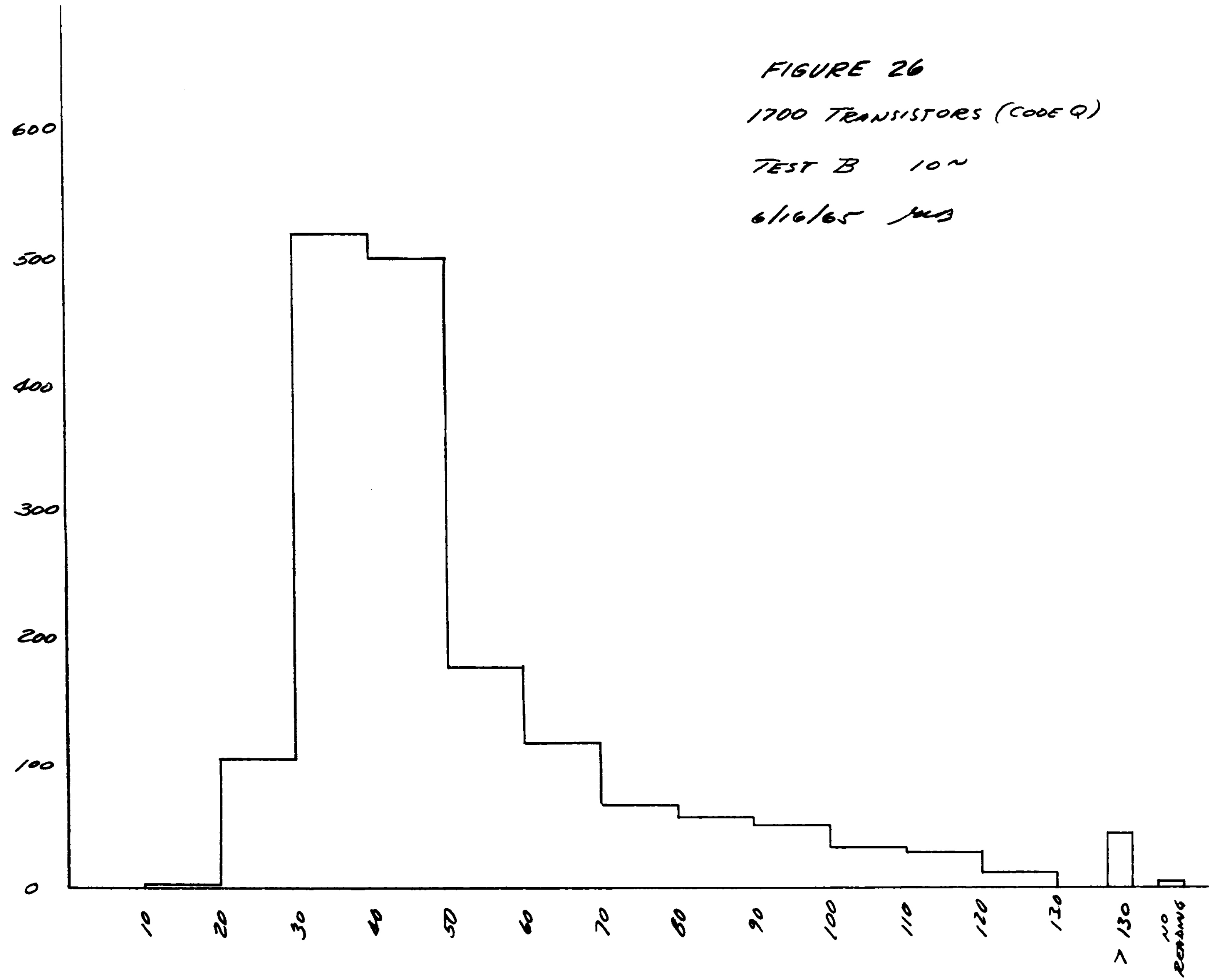


FIGURE 26
1700 TRANSISTORS (CODE Q)
TEST B 10~
6/16/65
600
500
400
300
200
100
0
10
20
30
40
50
60
70
80
90
100
110
120
130
> 130
NO READING

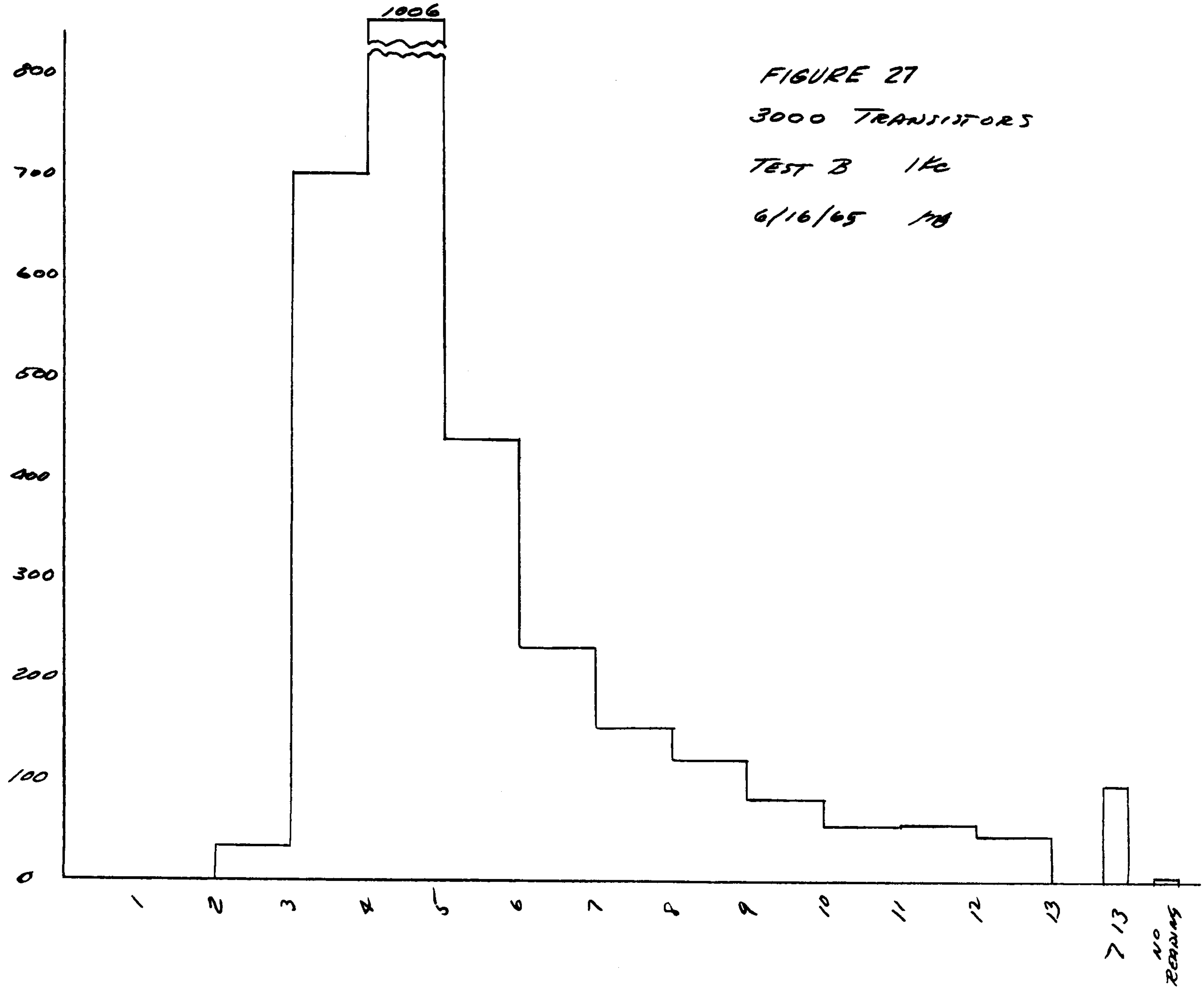


FIGURE 27
3000 TRANSISTORS
TEST B 1Kc
6/16/65 MB

Test B, Noise Voltage (10^{-9}) V/√~	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	>1300	
	8	47	89	89	79	60	36	24	16	14	5	4	5	27	
>130		4 / 4	17 / 17	16 / 16	11 / 11	14 / 14	4 / 4	1 / 1		1 / 1				12 / 12	80
120			9 / 9	4 / 4	11 / 11	7 / 7	2 / 2							1 / 1	34
110		3 / 3	3 / 3	3 / 6	3 / 11	3 / 11	2 / 2	3 / 3	2 / 2					1 / 1	23
100		1 / 1	3 / 4	3 / 14	3 / 22	3 / 10	3 / 9								16
90		3 / 6	3 / 6	3 / 21	6 / 35	3 / 19	3 / 4	3 / 4		2 / 2	1 / 1			1 / 1	31
80		3 / 3	3 / 17	6 / 37	3 / 24	3 / 11	3 / 8	2 / 2	1 / 1	1 / 1				1 / 1	26
70		3 / 7	3 / 28	6 / 33	6 / 35	3 / 10	3 / 8	2 / 2	1 / 1					2 / 2	29
60	1 / 1	3 / 15	6 / 40	6 / 71	6 / 45	3 / 26	3 / 7	3 / 4	2 / 2	1 / 1	2 / 2	2 / 2			38
50	1 / 1	3 / 13	6 / 76	9 / 117	6 / 70	6 / 46	3 / 29	3 / 8	3 / 6	3 / 3	1 / 1				44
40		6 / 55	12 / 196	15 / 258	12 / 208	6 / 88	6 / 38	3 / 17	3 / 11	3 / 4	1 / 1	2 / 2	5 / 5	3 / 3	77
30	3 / 5	9 / 93	18 / 286	15 / 228	9 / 112	6 / 51	3 / 15	3 / 7	3 / 4	3 / 5				4 / 4	76
20	3 / 3	6 / 55	6 / 71	3 / 15	3 / 14	3 / 3	1 / 1	1 / 1	1 / 1					2 / 2	29
10		3 / 3													3
0															

TEST A, NOISE VOLTAGE (10^{-9}) V/√~

FIGURE 28

CROSS PLOT OF 10 C.P.S. TESTS SHOWING TOTAL 3000 TRANSISTORS AND 500 UNITS SELECTED FOR STUDY

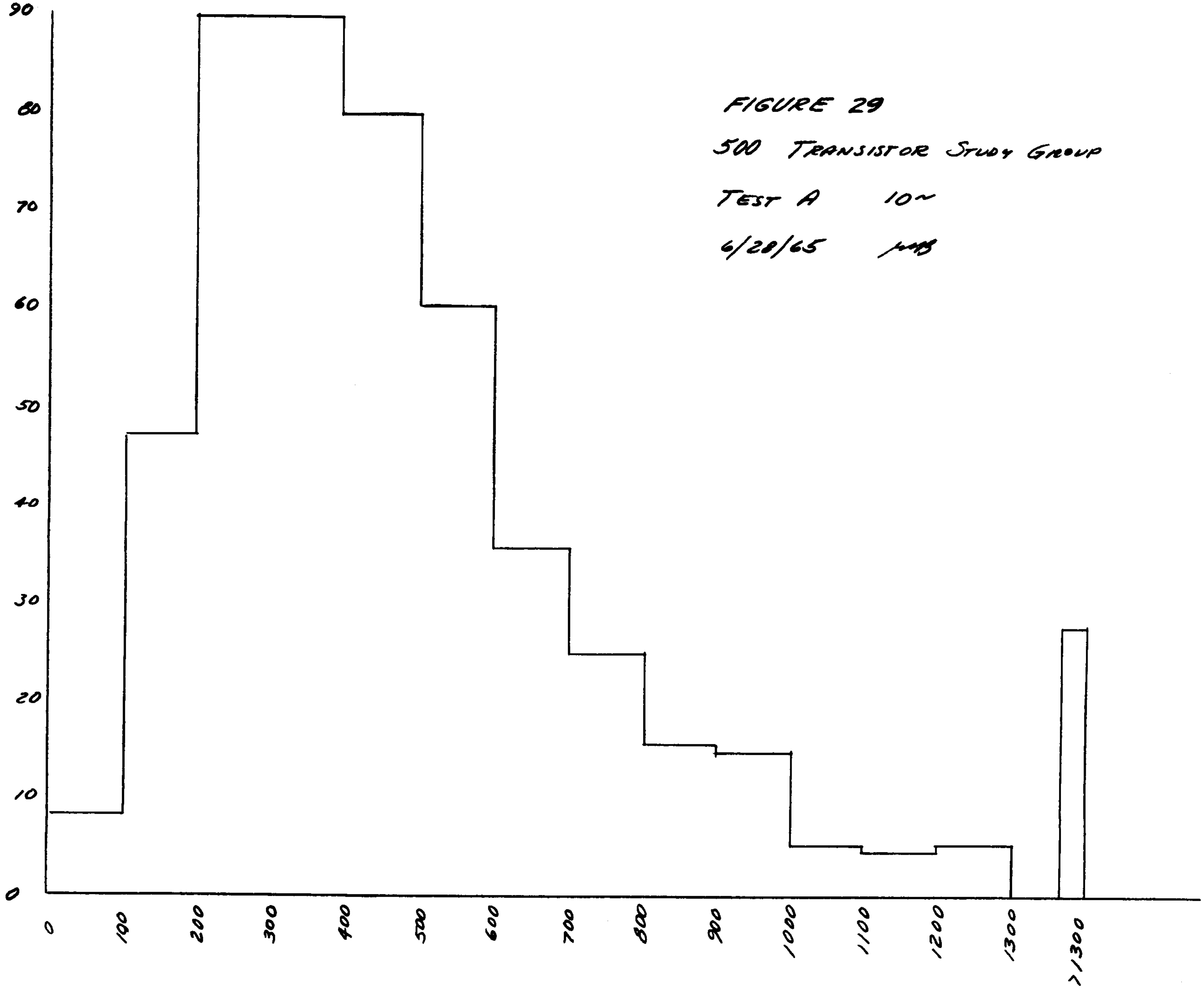


FIGURE 29

500 TRANSISTOR STUDY GROUP

TEST A 10~

6/28/65 MAB

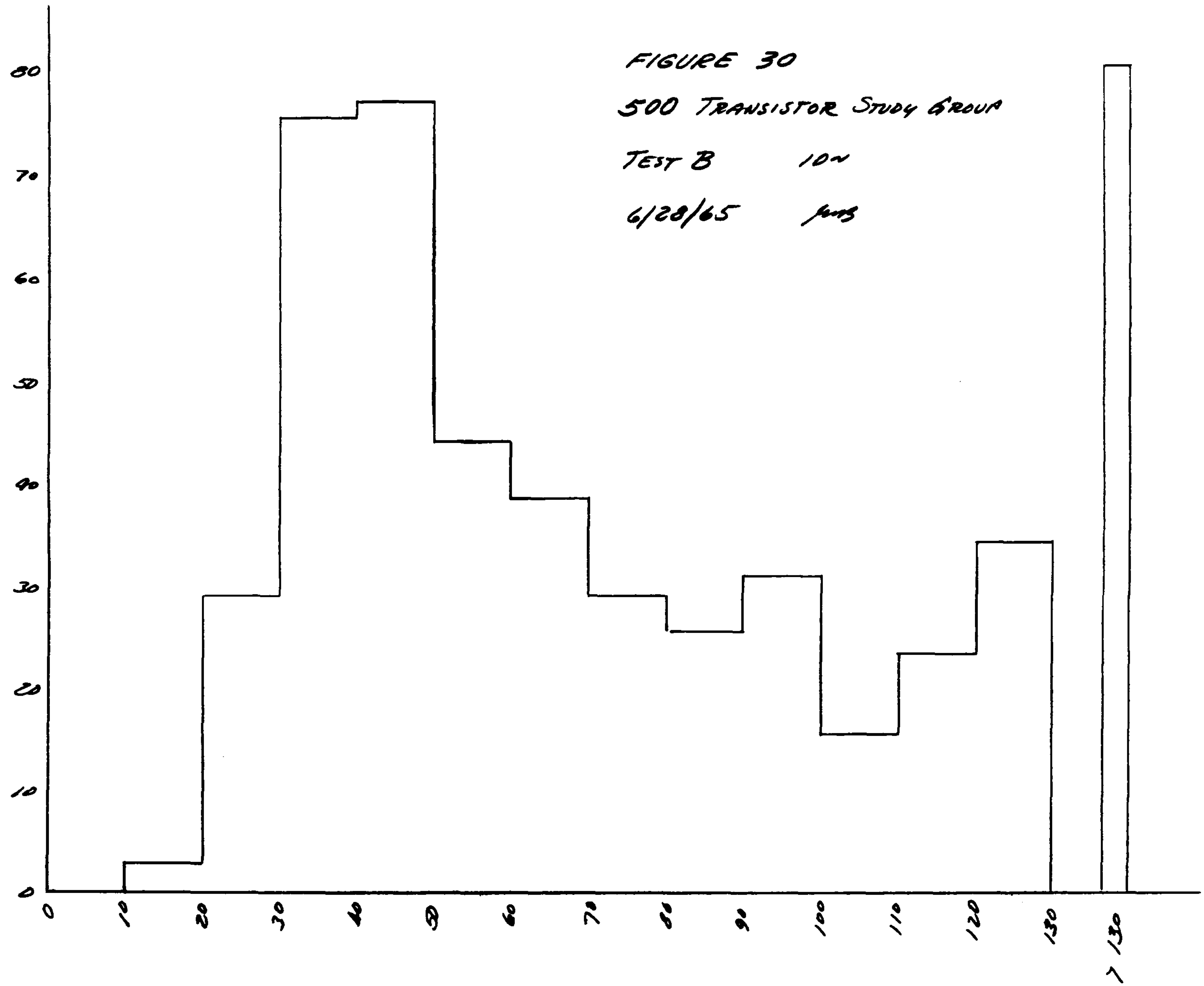


FIGURE 30

500 TRANSISTOR STUDY GROUP

TEST B 10~

6/28/65

FIGURE 31
HISTOGRAM
I_{CBO} DISTRIBUTION
500 TRANSISTORS, 2N1613
NAS5-9550

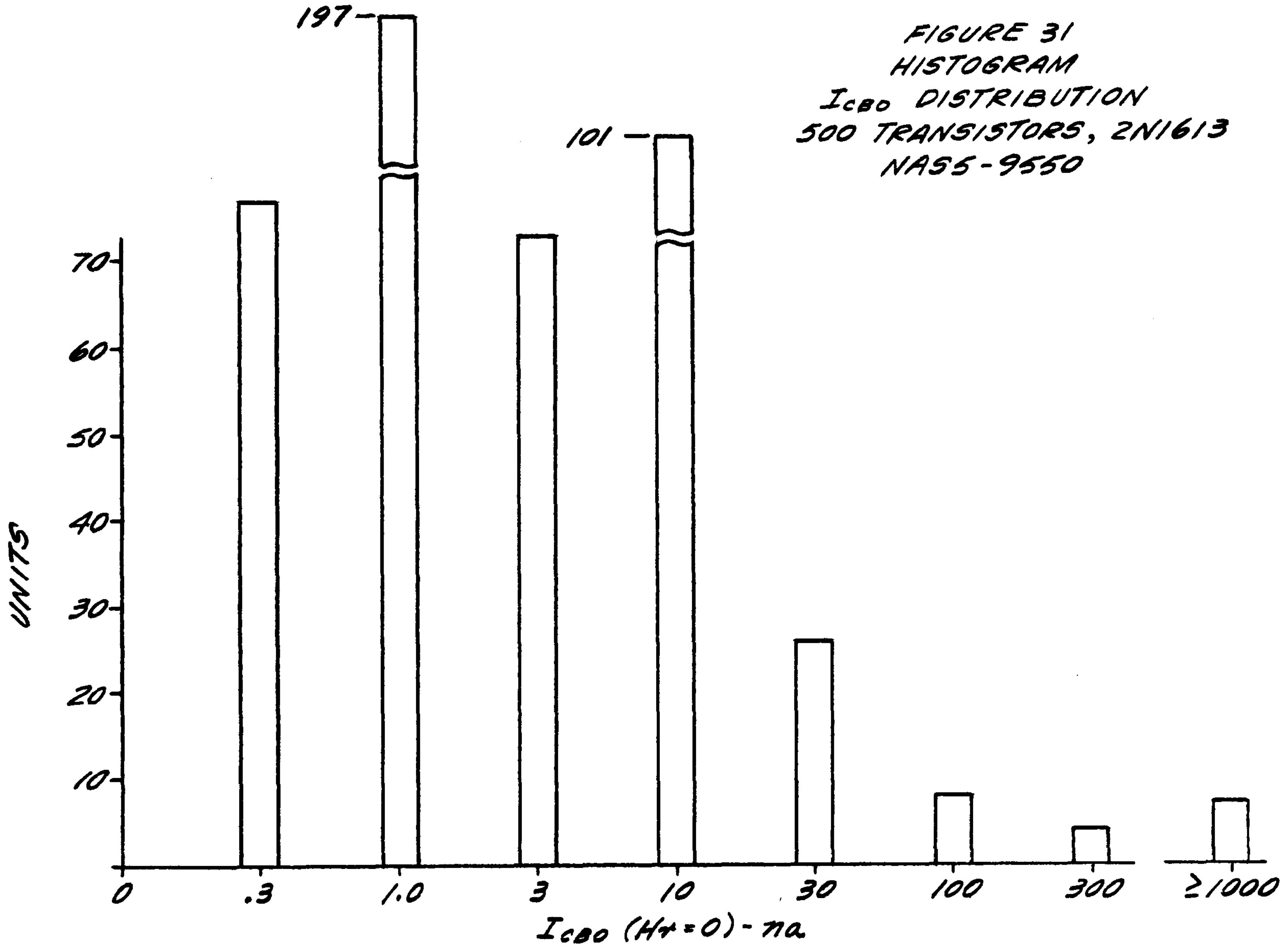


FIGURE 32
HISTOGRAM
I_{EBO} DISTRIBUTION
500 TRANSISTORS, 2N1613
NAS5-9550

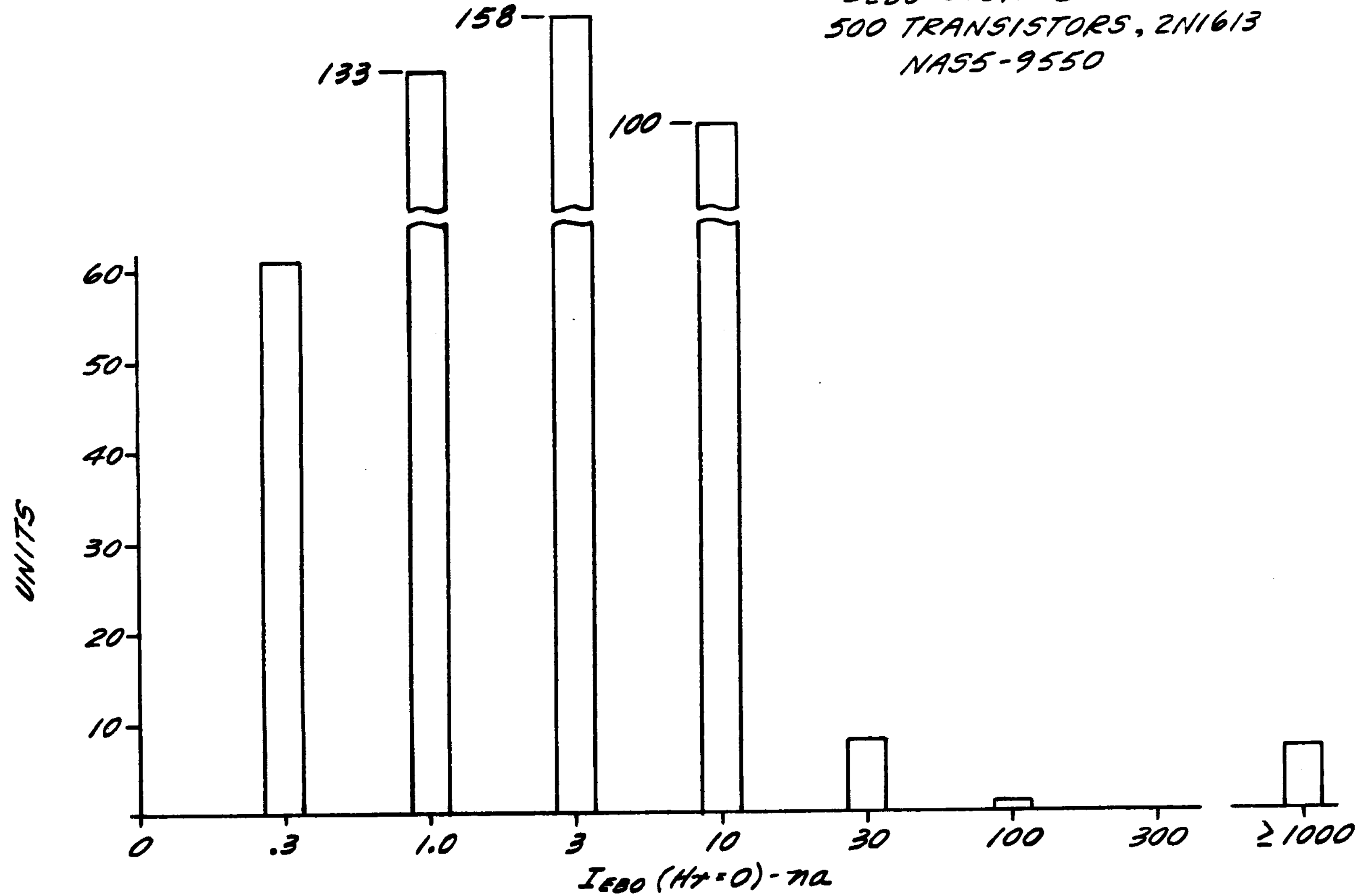


FIGURE 33
HISTOGRAM
h_{fe} DISTRIBUTION
154 TRANSISTORS, 2N1613
NAS5-9550

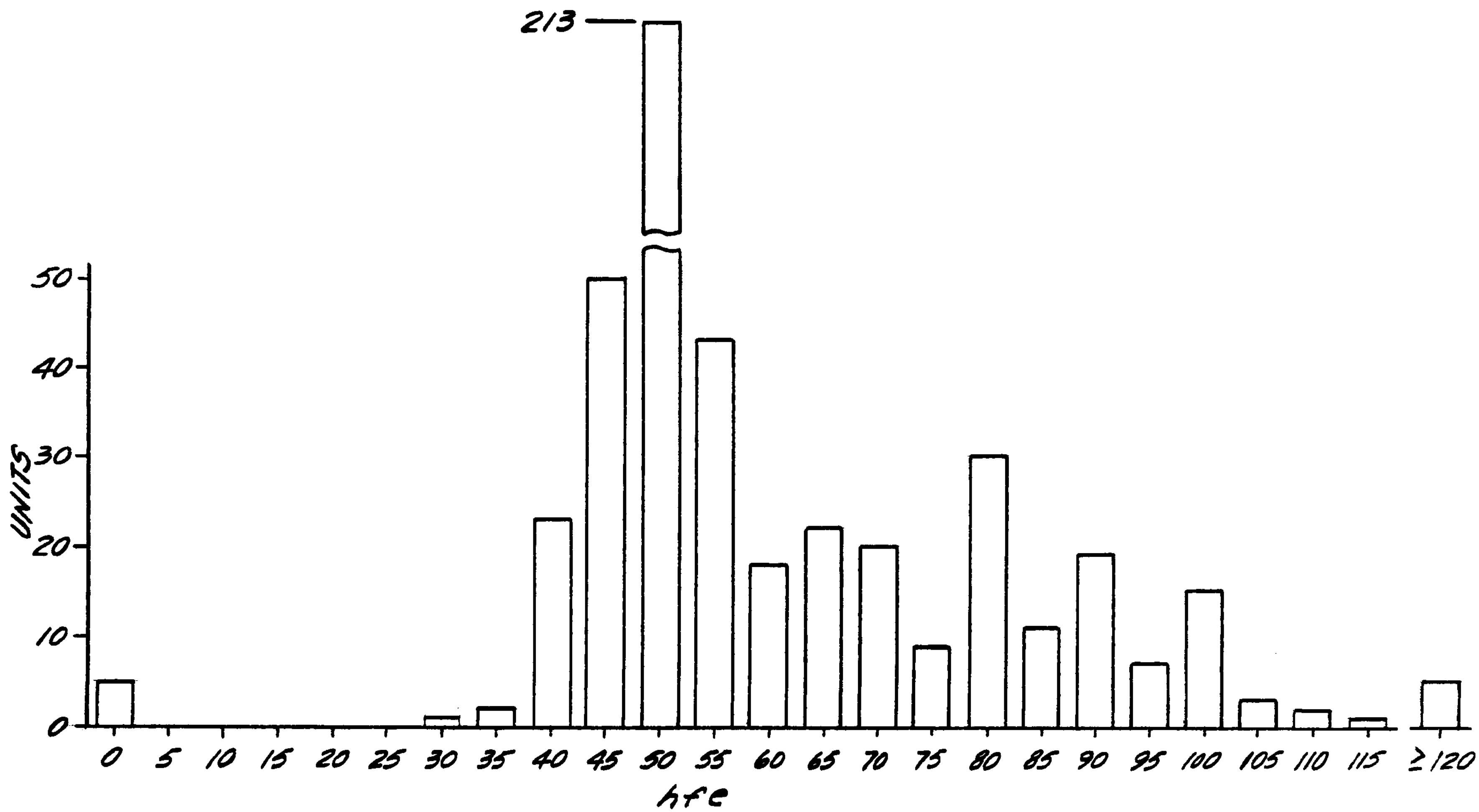


FIGURE 34
HISTOGRAM
FAILURE DISTRIBUTION
10 ~ TEST A (H+=0)

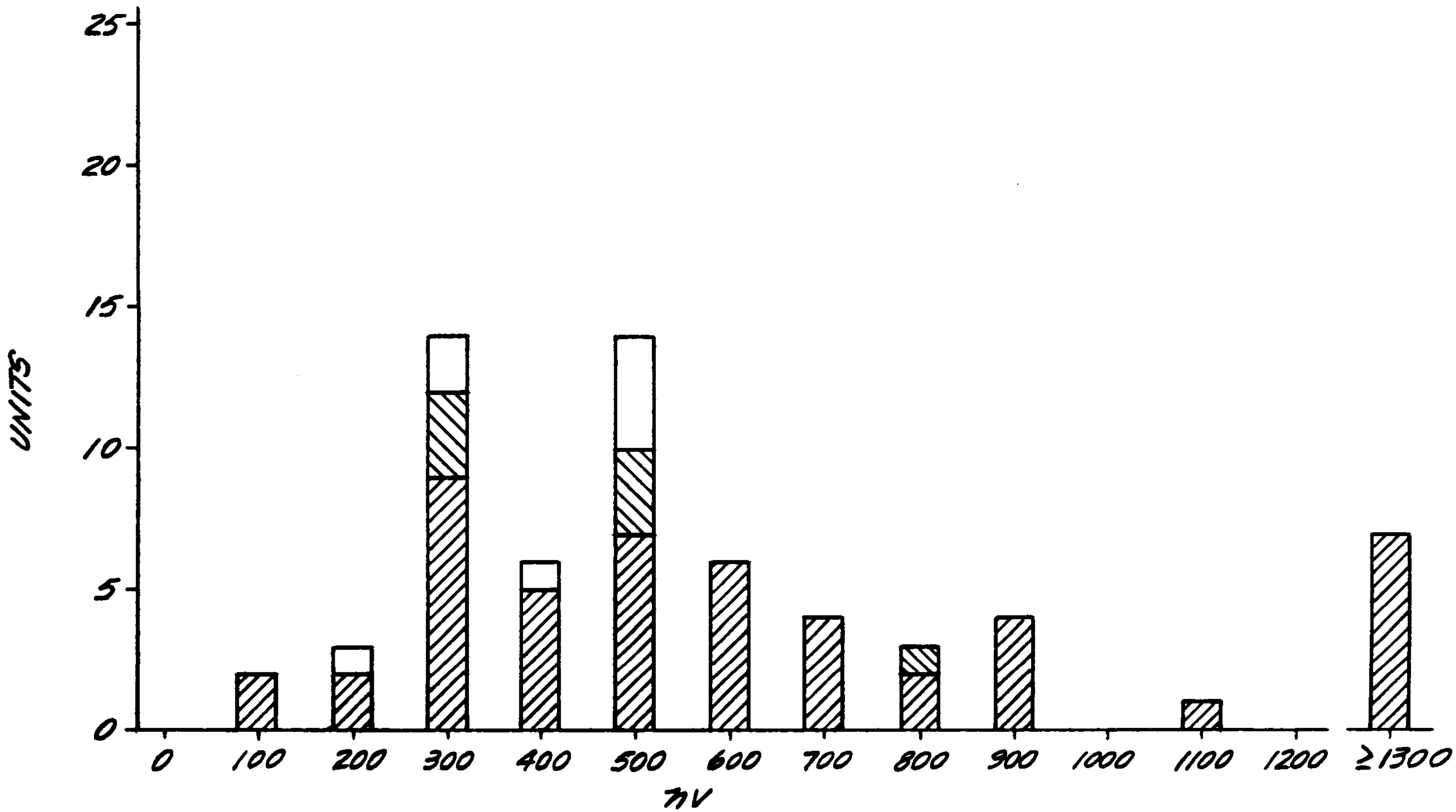


FIGURE 35
HISTOGRAM
FAILURE DISTRIBUTION
10~ TEST B (H+=0)

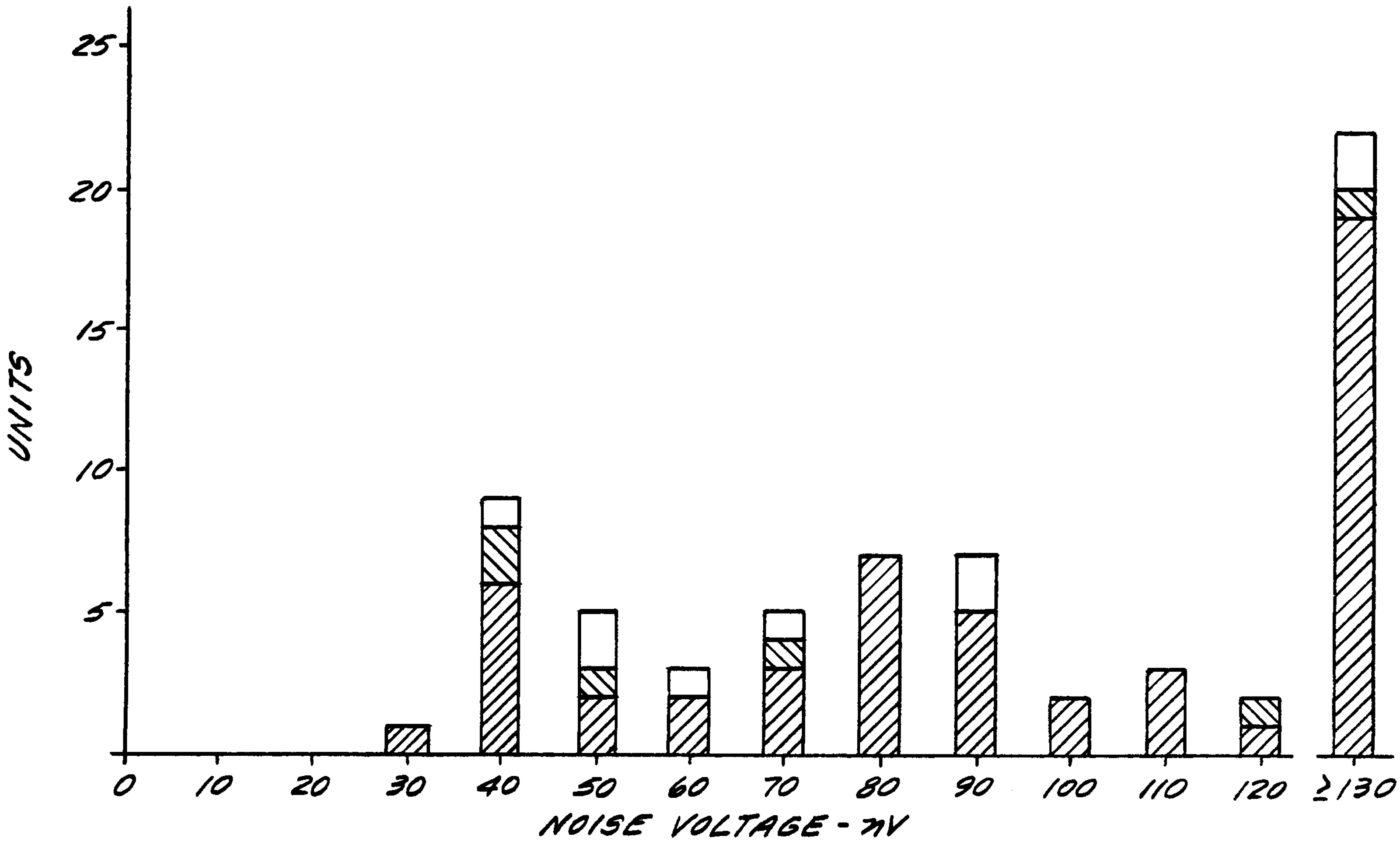


FIGURE 36
HISTOGRAM
FAILURE DISTRIBUTION
I_{CBO} (Ht=0)

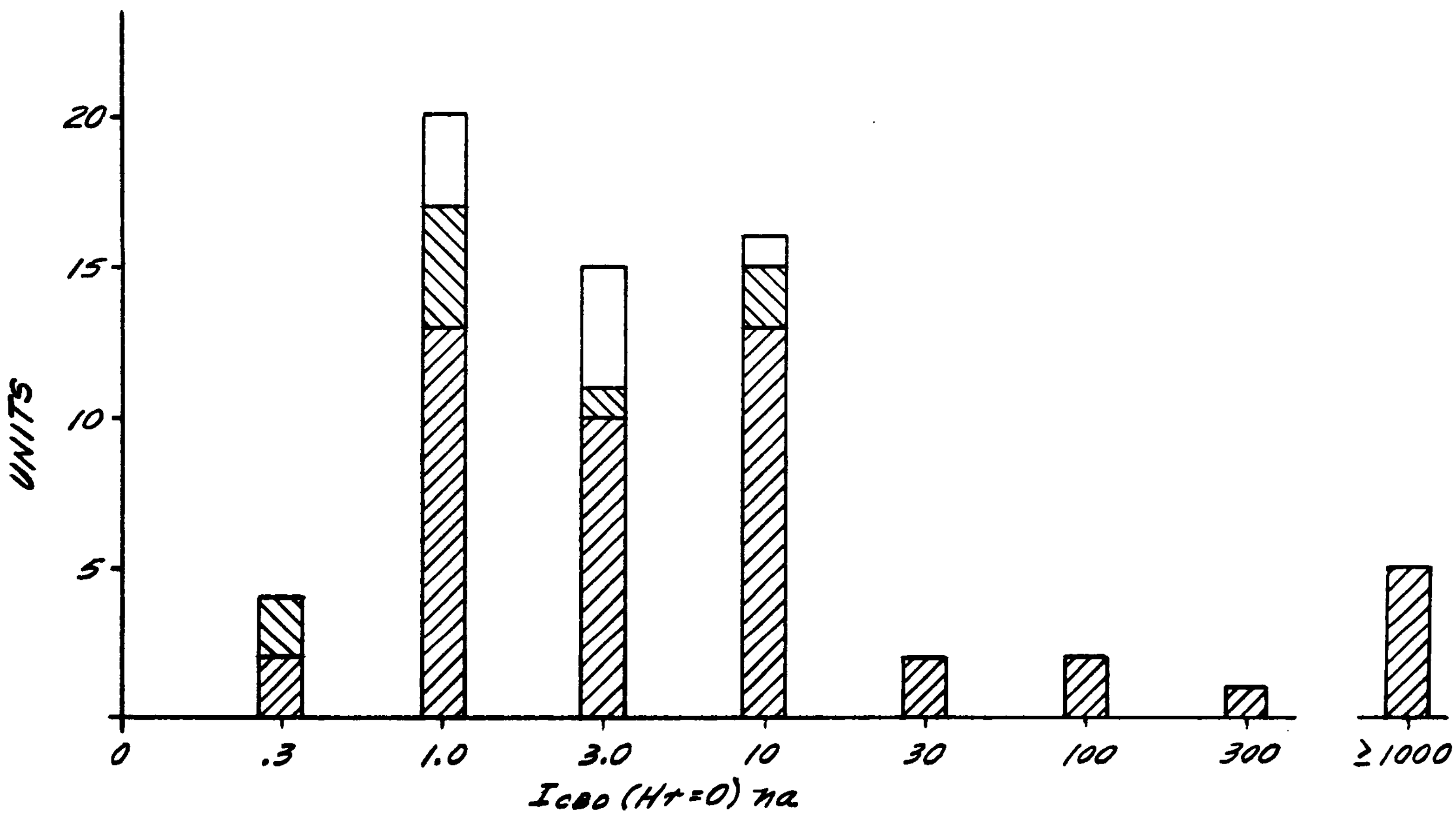


FIGURE 37
HISTOGRAM
FAILURE DISTRIBUTION
I_{EBO} (Hr = 0)

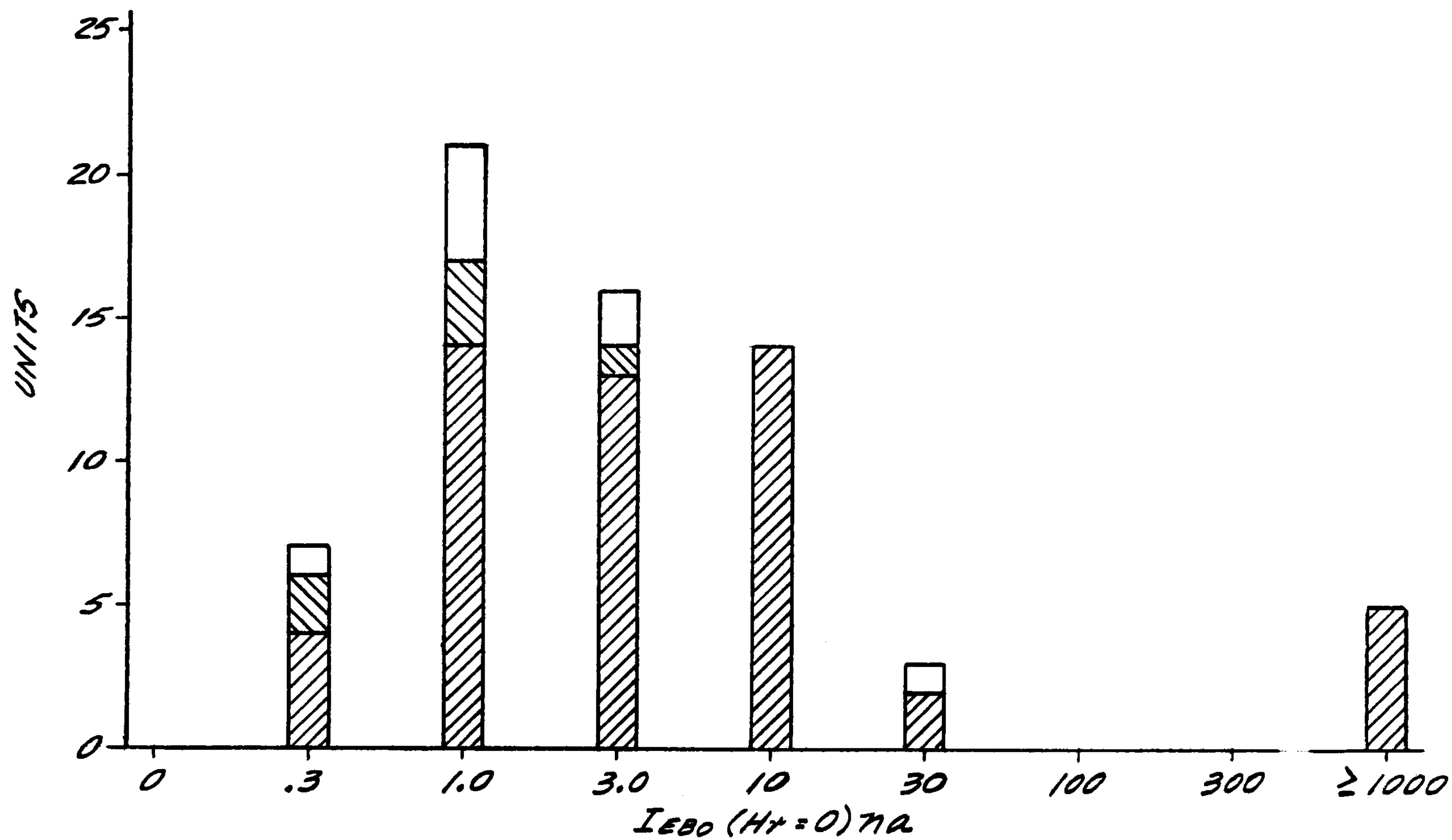


FIGURE 38
HISTOGRAM
FAILURE DISTRIBUTION
h_{fe} ($H_r = 0$)

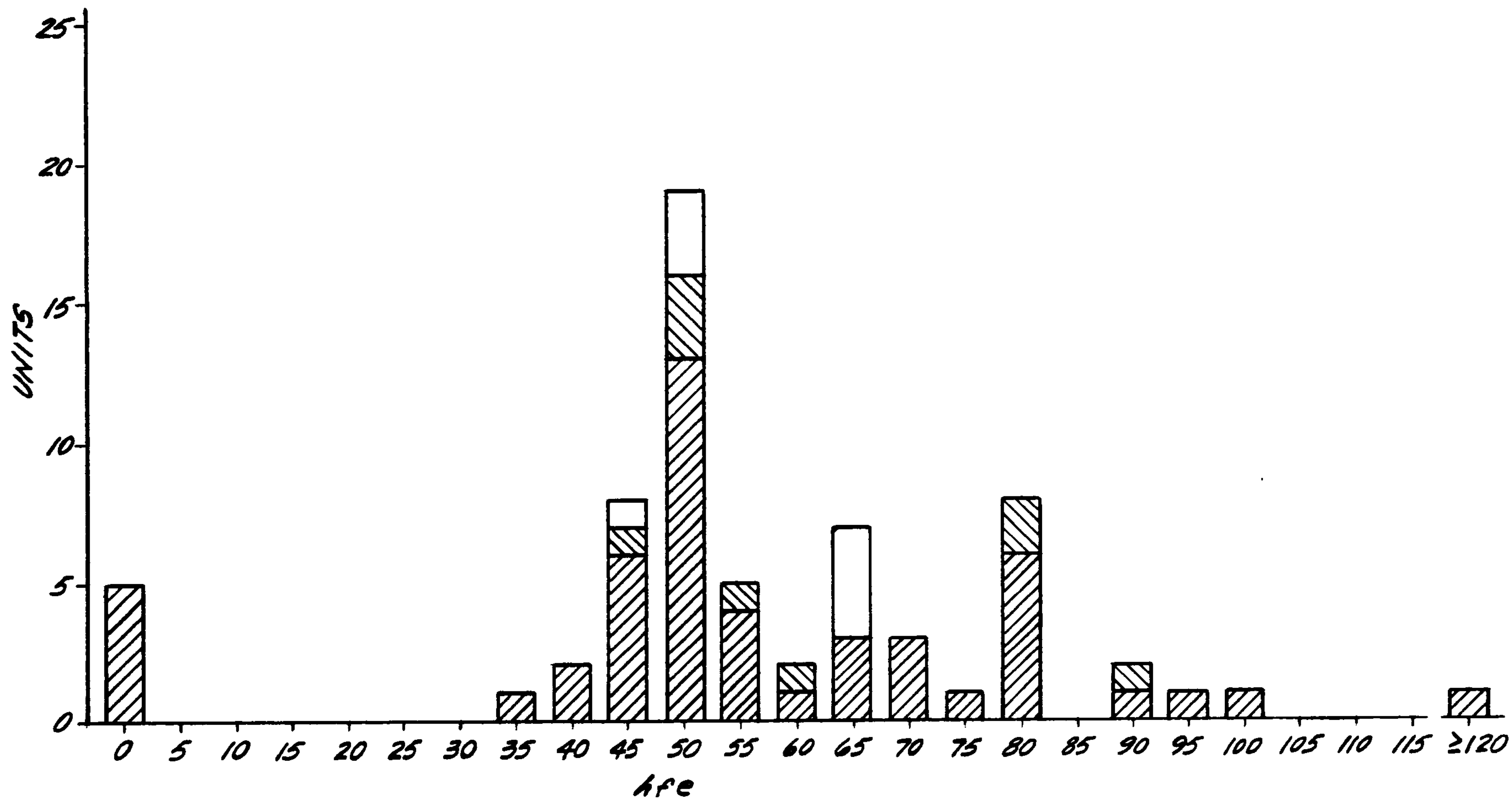


FIGURE 39

FAILURE RATE VS. TEST TIME

(500 UNITS LIFE TESTED)

FAILURE = $I_{CBO} > 100$ na

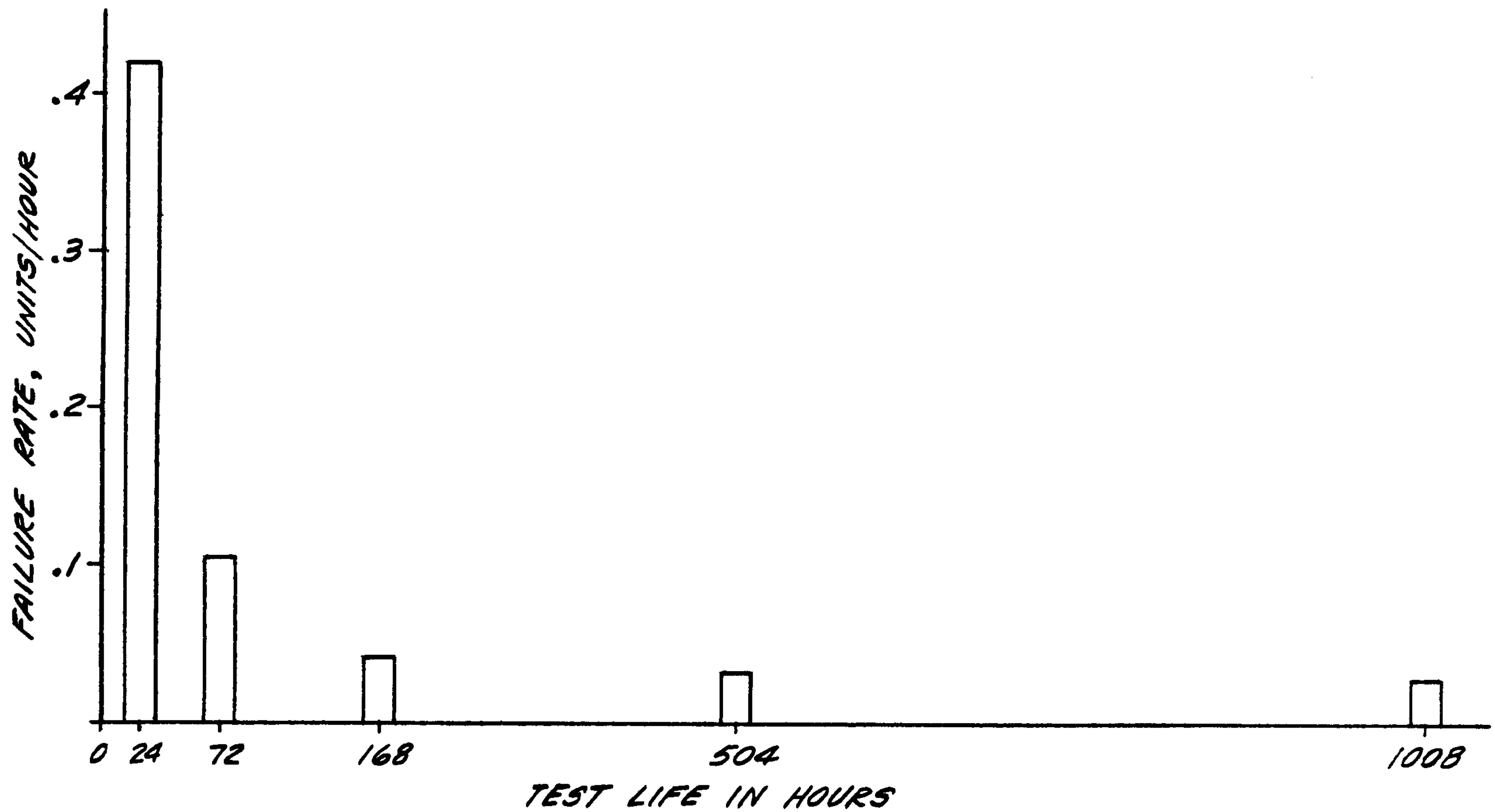


FIGURE 40
FAILURE VS. TEST TIME
FAILURE: $I_{CBO} > 100\,na$

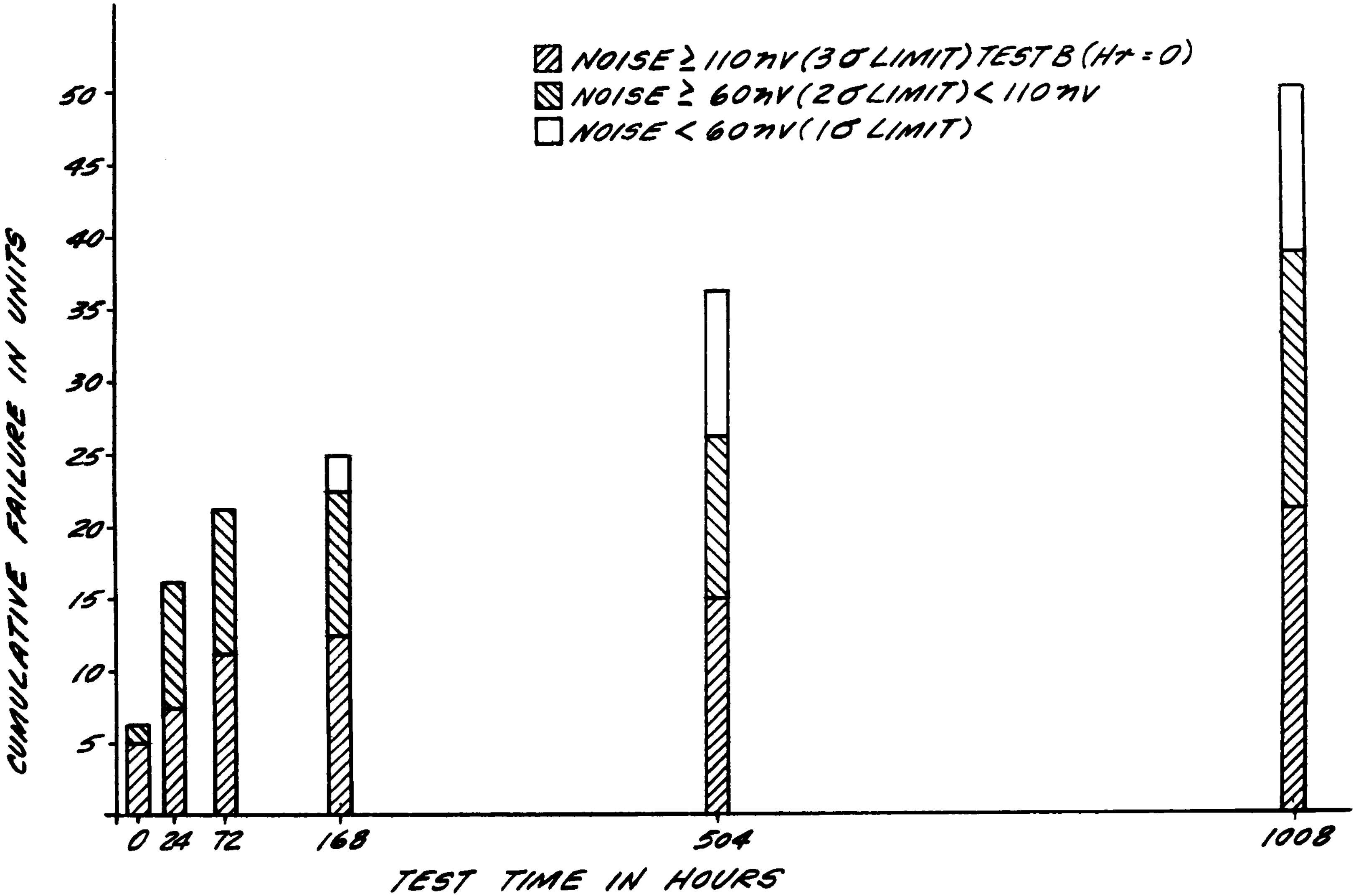


FIGURE 41
HISTOGRAM
10 ~ TEST A (Hr = 24)

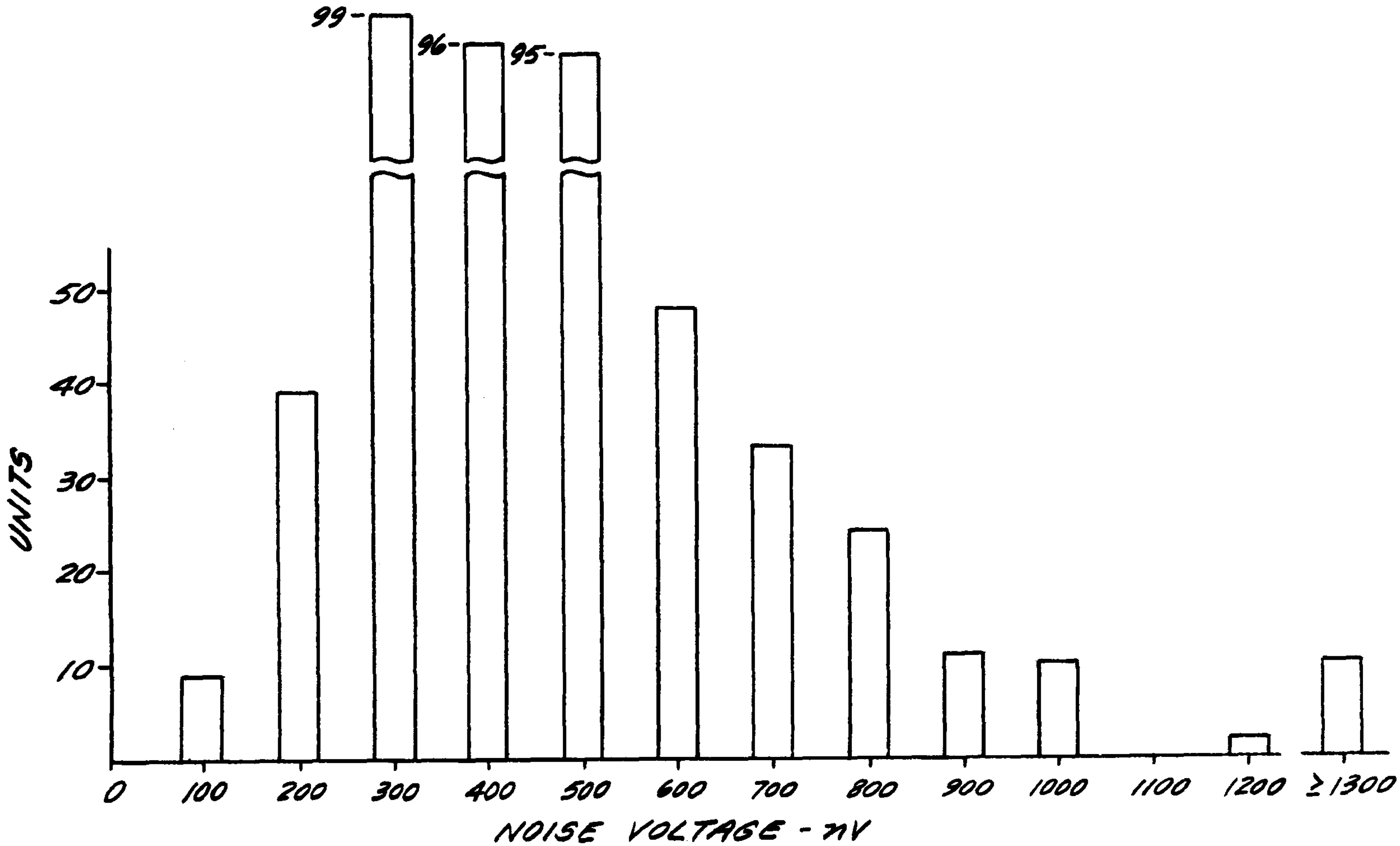


FIGURE 42
HISTOGRAM
10~ TEST B (Hr = 24)

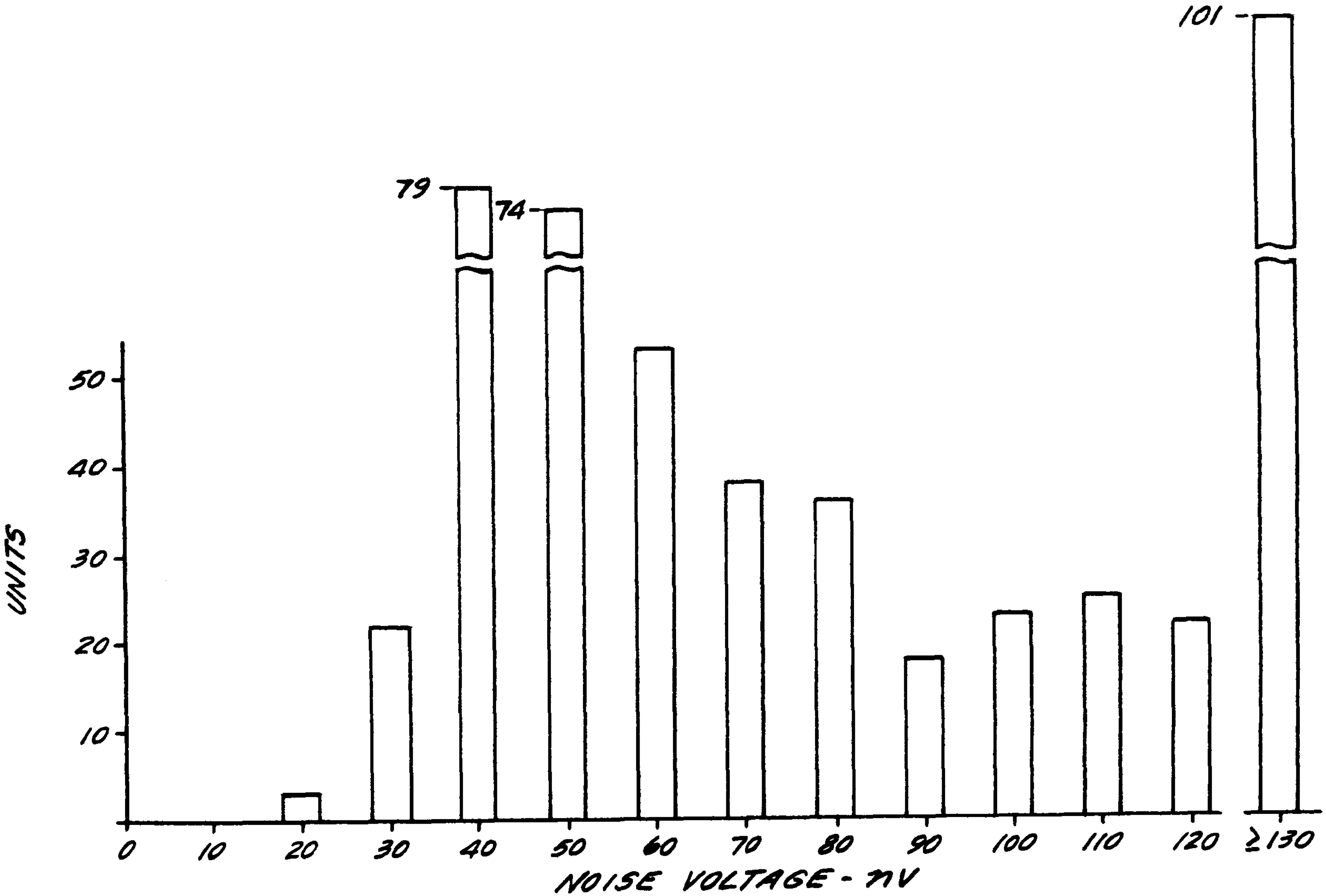


FIGURE 43
HISTOGRAM
FAILURE DISTRIBUTION
10Ω TEST A (Ht=24)

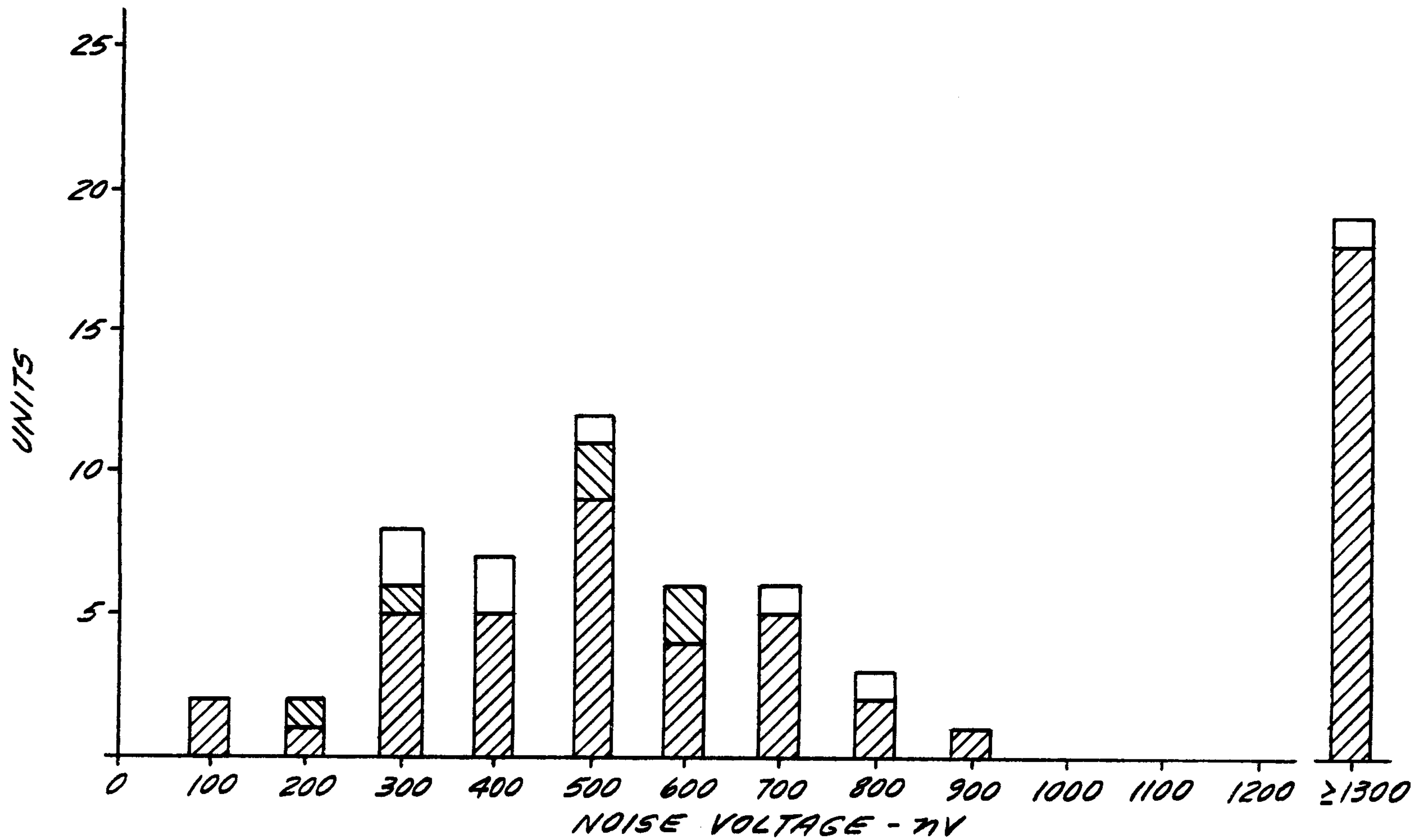


FIGURE 44
HISTOGRAM
FAILURE DISTRIBUTION
10 ~ TEST B (Ht=24)

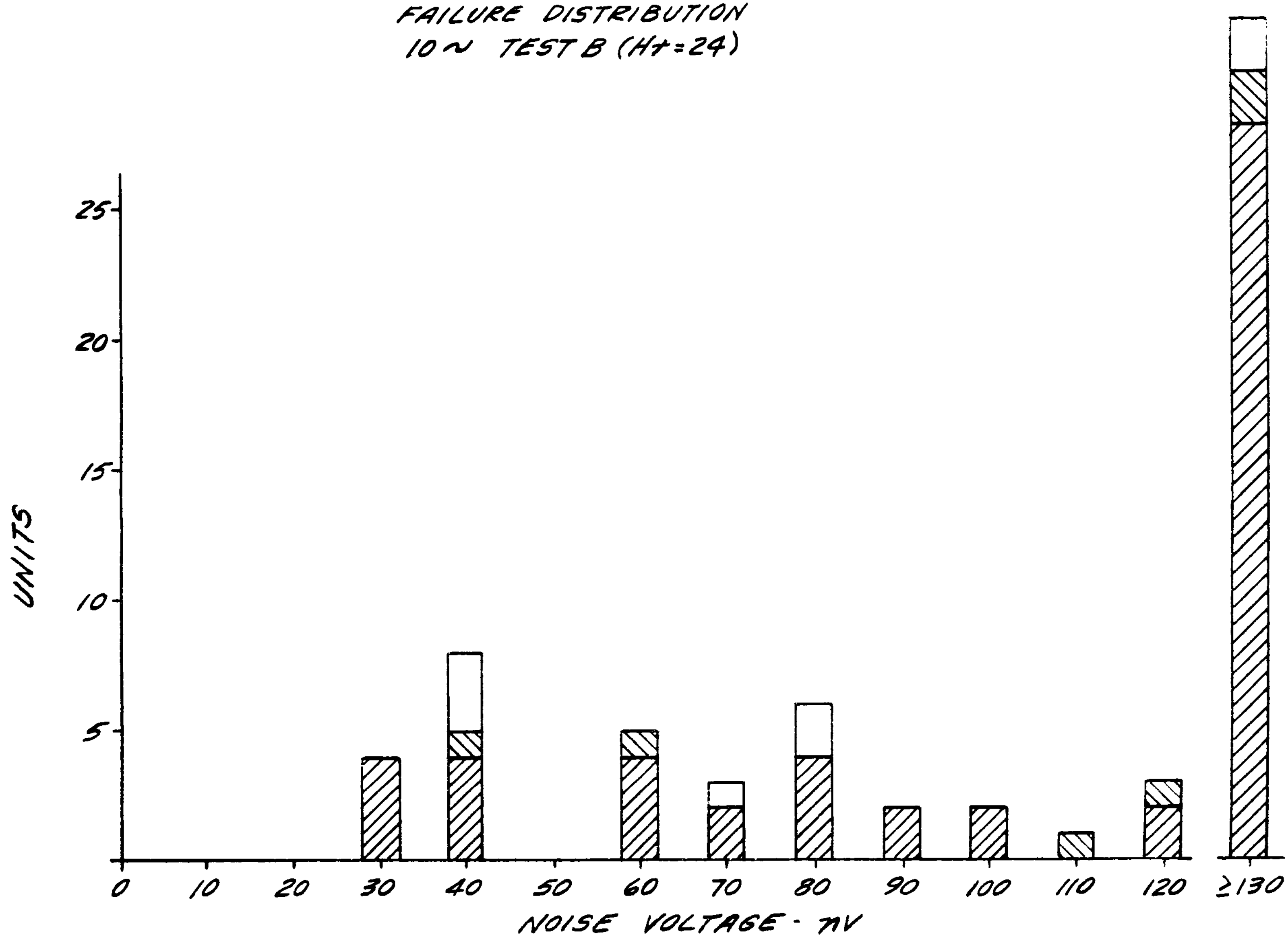


FIGURE 45
HISTOGRAM
FAILURE DISTRIBUTION
I_{CBO} (Hr = 24)